

2000

# Female High School Biology Students' Biofilm - Focused Learning: the Contributions of Three Instructional Strategies to Patterns in Understanding and Motivation.

Jo Dale hill Ales

*Louisiana State University and Agricultural & Mechanical College*

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**FEMALE HIGH SCHOOL BIOLOGY STUDENTS'  
BIOFILM-FOCUSED LEARNING:  
THE CONTRIBUTIONS OF THREE INSTRUCTIONAL STRATEGIES TO  
PATTERNS IN UNDERSTANDING AND MOTIVATION**

**A Dissertation**

**Submitted to the Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
in partial fulfillment of the  
requirements for the degree of  
Doctor of Philosophy**

**in**

**The Department of Curriculum and Instruction**

**by**

**Jo Dale Hill Ales  
B.S., Louisiana State University, 1970  
M.N.S., Louisiana State University, 1972  
December, 2000**



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## **ACKNOWLEDGMENTS**

There are so many people to thank for supporting me along this journey. Dr. James H. Wandersee, William H. LeBlanc Teaching Fellow in the Department of Curriculum and Instruction at Louisiana State University, has been my advisor and directed along the way. He is an exemplary teacher, friend, and mentor who has supported me with wise advice. Dr. Wandersee's patience and gentle Tiger spirit encouraged me and helped me grow both as a teacher and a researcher.

My microbiology mentor 28 years ago was the late Dr. Robert Amborski. He along with Dr. M.D. Socolofsky and other giants in their field instilled in me an unbounded interest of microbes. Today Dr. Eric Achberger's support and guidance keep that interest growing, though in a more molecular way. Dr. Achberger first taught me how to run an electrophoresis analysis of DNA and has helped me bring new ways of learning to my high school biology classroom. When I returned to teaching nine years ago he fast-forwarded me into the 20<sup>th</sup> century of microbiology learning. Dr. Achberger never gives up on high school science teachers. Other members of my committee whose knowledge and expertise have helped me more than they realize are the members of the Department of Curriculum and Instruction; Dr. Ron Good who has me thinking more deeply about cognition and evolution, Dr. Byron Launey who supports what I do in the classroom, and Dr. Ken Denny who has challenged me to think. Dr. Mohamed Noor, evolutionary biologist in the College of Basic Sciences, has also offered invaluable advice. I am thankful to have had such a scholarly team to lean upon.

My family has traveled this journey with me and supported me throughout it. My parents, Dale and Skee Hill are still cheering me on after all these years. My loving husband, John has helped me in so many ways and most importantly is always there to listen. He is a rock that supports me even when it means less time with our family. My children, Elizabeth and her husband Norman, Laura, and John Forrest, have encouraged me to do my best. I owe special thanks to my friends and colleagues who have patiently listened to all my talk about my research. Jackie Charles, Jackie Zeller, Sister Ursula Harelson and members of the science department, Sr. Judith Brun and the A Team, Paula Calderon, Nan Murtagh Morgan, Rebecca Stagg, Lori Harper, Beleta Bischoff and the Tech Team, fourth hour lunch, and my coffee group have contributed to this research in many ways. Also Marcella Hackney and Sharon Flannagan have offered advise from their own experiences. I am also grateful to Claudia Fowler and the other members of the Dream Team who accepted biofilms for the Enviro-Tacklebox™ project. Finally, the students I teach have been the driving force behind anything that I have accomplished in the field of science education. There is such joy in teaching and it comes from seeing the progress of those who learn. Their excitement and energy have made me enthusiastic about learning. I am truly blessed to have all of these wonderful people in my life.

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## **ABSTRACT**

This exploratory study examined three instructional strategies used with female high school biology students. The relative contributions of the strategies to student understanding of microbiology and motivation in science were analyzed. The science education community targeted underachievement in science by implementing changes in content and practices (NRC, 1996). Research suggested that teachers facilitate learning environments based on human constructivism (Mintzes, Wandersee, & Novak, 1997) that is rooted in meaningful learning theory (Ausubel, Novak & Hanesian, 1978). Teachers were advised to use both visual and verbal instructional strategies (Paivio, 1983) and encourage students to construct understandings by connecting new experiences to prior knowledge.

The American Society for Microbiology supports the study of microorganisms because of their prominence in the biosphere (ASM, 1997). In this study, two participating teachers taught selected microbiology concepts while focused on the cutting edge science of biofilms. Biology students accessed digitized biofilm images on an ASM web page and adapted them into products, communicated with biofilm researchers, and adapted a professional-quality instructional video for cross-age teaching. The study revealed improvements in understanding as evidenced on a written test; however, differences in learning outcomes were not significant. Other data, including student journal reflections, observations of student interactions, and student clinical interviews indicate that students were engaged in cutting edge science and adapted biofilm images in ways that increased understanding of microbiology (with respect to both science content and as a way of knowing) and motivation. An ASM

CD-ROM of the images did not effectively enhance learning and this study provides insights into what could make it more successful. It also identifies why, in most cases, students' E-mail communication with biofilm researchers was unsuccessful. The positive experiences of successful students indicate that teacher management could maximize the benefits of experiencing cutting edge science this way. Cutting edge science can be used to make science more relevant to students, enhance science learning, and insure a more scientifically literate society. Cross-age teachers effectively adapted an instructional video, communicated science, and increased their understanding of selected microbiology concepts and self-confidence. They also increased or maintained their motivation to study science.

## **INTRODUCTION**

### **A Need for Science Education Reform**

...knowledge is not a simple transcription of real world objects and events that can be faithfully communicated either from direct observation of nature itself or from one person to another. Instead, knowledge is an idiosyncratic, hierarchically organized framework of interrelated concepts that is "built up" by scientists and science students over time. (Mintzes, Wandersee, & Novak, 1997, p.52)

The 1983 declaration of a crisis in science education (National Commission on Excellence in Education [NCEE], 1983) resulted in an ongoing reform effort to improve the learning of science. Indications are that comprehensive change may be slowly occurring (National Science Teachers Association [NSTA], 1998) and the debate over how to effect positive change continues. Science teachers have the potential to improve science education when guided by a theoretical framework consisting of Ausubel's meaningful learning theory (Ausubel, Novak & Hanesian 1978) and human constructivism (Mintzes, Wandersee, & Novak, 1997). Meaningful learning theory heavily influenced human constructivism, which links understanding how human beings make meaning with the tools that science teachers can use in the classroom.

### **The Need For This Project**

The history of science education, impacted by many social factors (Mintzes et al. 1997) underscores the need for this research. Student underachievement in science (Chan, Doran, & Lenhardt, 1999), gender differences in learning science and career selection, and the need for a more science literate society initiated this study. Science teachers have been challenged to move science education into the 21<sup>st</sup> century, an information rich age, in which citizens will have real time access to cutting edge

science. After development of the National Science Education Standards (National Research Council [NRC], 1996), the science education reform movement progressed to the implementation stage and science teachers were given the responsibility to improve science education. Well-intended scientists, science educators, and others provided a multitude of curricula, instructional strategies, educational products (tools), and other resources to support the changes that reform called for. But, as Mintzes et al. (1997) pointed out, classroom change is only implemented by effective science teachers. These already overworked teachers must make decisions about which resources to use. This study grounded in human constructivism (Mintzes et al. 1997) makes the assumption that science teachers who combine educational theory with classroom practices are empowered to be effective facilitators of science learning. This contrasts with the view of some educators that educational theory is separate from pedagogy (Pinar, Reynolds, Slattery, & Taubman, 1996).

The goal of this exploratory research was to study how selected female, high school biology students learned about microbiology when focused on the concept of biofilms. A secondary goal was to observe any obvious changes in motivation towards learning science that the female high school biology students exhibited. This study focused on how female high school biology students learned basic microbiology concepts and principles through the use of a three-pronged instructional strategy in a teacher-facilitated learning environment that involved these students in

- (a) studying the cutting edge science of biofilms and interactive communication with biofilm researchers,

- (b) viewing and analyzing an instructional video and adapting it for cross-age teaching of middle school students, and
- (c) and judiciously incorporating biofilm images into a student designed project, which was also to be used in cross-age teaching.

### **Selection of Instructional Strategies**

The study combined the framework of science education reform with three instructional strategies applied in five female high school biology classrooms under best learning conditions. The learning environments and strategies used were not arbitrary but purposely selected based on the worldview of the teacher-researcher. This worldview perceives teachers whose practices are influenced by educational research as having more innovative classrooms where instructional strategies are flexible and incorporate novel ideas. Guided by the National Science Education Standards (NRC, 1996) they emphasize quality over quantity, strive for understanding instead of rote memorization of isolated information, facilitate student-centered learning, focus on relevant science concepts, employ inquiry-based explorations, use authentic assessments, and insure equity for all.

When teachers implement science education reform they are empowered to make decisions and choose instructional strategies to use. This includes selecting appropriate technology tools for learning and relying on personal classroom experiences to make these choices. The study addresses gender equity in science education and the relative underachievement of girls in science and the low numbers of females entering science careers. The body of recorded research on gender and science has shown that science is considered to be a masculine domain (Kleinman, 1998). The effect of this



interpretation has been that fewer women pursue careers in science. The teacher-researcher has taught science in two all female high schools for 11 years and has an interest in encouraging female participation in science careers and raising the level of academic achievement for females in science.

### **Biofilms: The Core Concept**

The concept of biofilms was used as a novel approach to studying microbiology in order to involve students in cutting edge science that is relevant to their daily lives. Biofilms are communities of bacteria and other organisms that might include algae, protozoans, and higher organisms such as insects. The bacteria secrete a polysaccharide slime that serves to attach the biofilms to different surfaces located in water or at water-air interfaces and to protect the bacteria from destruction. This living film is resistant to attack from chemicals and physical action and promotes the growth of its members through increased access to nutrients. Biofilms, though part of an unseen world, are relevant to female high school biology students because they can cause infections, tooth decay, and environmental and industrial problems that impact their lives. They are also used in developing technologies to solve medical and environmental problems. The study supports the American Society for Microbiology's efforts to increase microbial literacy among the public and improve K – 12 microbiology education.

The concept of biofilms was selected because of the teacher-researcher's interest in and expertise in microbiology. Observations through personal teaching experiences have found that microbiology concepts are often neglected in high school biology classes because of the teacher's lack of knowledge about the subject and insufficient

time and equipment to devote to growing and analyzing pure cultures of bacteria. The few professional development activities related to microbiology focus mainly on contemporary uses of microorganisms in the area of genetics such as transformation and DNA analysis. There is a need to introduce biofilms to high school students because they are relevant to students' lives and have only been presented at the high school level to a limited degree. Future citizens will have to make decisions based on their understanding of the use of biofilms in new technologies and their impact on health. It was thought that the use of the novel concept of biofilms would stimulate interest in microbiology and engaged the students more effectively than other topics while teaching them about the effects of medical, dental, and environmental biofilms and the use of new technologies that use biofilms. The instructional strategies that were used in the study developed from a personal vision to increase student understanding of selected microbiology concepts and motivate students to learn science.

### **Communication with Biofilm Researchers**

Communication with biofilm researchers was considered important to this study because advances in telecommunications have increased access to these researchers. It was thought that students could learn to communicate science by entering the science domain through E-mail and experience real time science through these researchers' experiences. Interactive dialogue can enhance meaningful learning and it was anticipated that knowledge would be gained about how to facilitate this dialogue. The students and scientists would become a community of learners. There has been little research on communicating with scientists and there is a need to tap this underutilized resource.

### **Adaptations of Biofilm Images**

The teaching strategies in the study also employed an American Society for Microbiology (ASM) digitized biofilm imagebase on a CD-ROM and a web page accessed through the Internet. Though biology is a more visual science than others visualizing science is a primary concern for all science educators. Effective teachers help students learn how to visualize abstract concepts, interpret visual representations, and to adapt these visual representations in ways that enhance meaningful learning. The way a student experiences a visual image enables the student to construct understandings about it. Higher quality visual representations are more successful at promoting understanding. Student participants were presented with images of biofilms that they adapted into instructional biofilm image products. The students became experts on their selected biofilms and it was hoped that this would increase interest and motivation in science. Adapting images would decrease the rote memorization of isolated terms and reveal the broader picture of biofilms and the interrelationships between members of the community, with other organisms, and with the physical and chemical environment in which they live. Some students also used processing and presentation software, microscopes, and a microscope video camera with a TV display monitor. Combined with the concept of biofilms these strategies engaged female high school biology students as they collaborated to construct understandings of selected microbiology concepts during the unit on ecology.

### **The Instructional Video**

The teacher-researcher has been involved in curricula development for several years. As a member of the content team of the local public television middle school

environmental science project, Enviro-Tacklebox™, the teacher-researcher proposed and assisted in the development of the video. This product was based on sound educational principles and it was thought that it would successfully contribute to microbiology learning by high school students as well as middle school students. Personal experience has shown that a contemporary video can bring students into the science domain partly through the use of visual representations and that teachers often minimize the educational potential of videos. In many cases, videos are used when the teacher is absent to keep the students occupied. Knowing the amount of time, expense, and knowledge that went into developing the instructional video used in the study, the teacher-researcher hoped that its use would contribute to understandings of how to effectively use instructional videos in the science classroom.

### **Cross-Age Teaching**

A final strategy was to have selected students adapt their biofilm image products and the instructional video to teach middle school students (cross-age teaching) the selected microbiology concepts. Most research on cross-age teaching has involved older students tutoring younger students and re-teaching concepts that they were presented in class. Cross-age teaching allows older students to adapt information and develop quality explanations to present new information to younger students. They would become mentors or teachers for these younger students. There is a large amount of research on peer teaching through collaboration (Brown, 1994; Meloth & Deering, 1994; Swing and Peterson, 1982); however, more research on cross-age teaching is needed to determine whether cross-age teaching can enhance science learning.

## **Research Questions and Overview of Research Study**

### **Research Questions**

This study addressed the following research question: How do biofilm-focused instructional strategies used with selected female, high school biology students contribute to (a) patterns in their understanding of selected microbiology concepts and principles, and (b) their motivation to study science?

The subquestions were:

1. Does the cutting edge science of biofilm research and interactive communication with biofilm researchers help engage these female high school biology students in learning microbiology?
2. How do these high school biology students' instructional adaptations of an instructional video on biofilms for middle school students reflect their own progress in meaningful microbiological learning?
3. How do these cross-age teachers (female high school biology students) use a Society for Microbiology (ASM) biofilm imagebase as an instructional tool to accomplish their goals?

### **A Gowin's Vee Diagram of the Research**

A Gowin's Vee Diagram (see Appendix A) was constructed to aid in developing and understanding the methods that were used in this study (Novak & Gowin, 1984). The research question and subquestions are listed in the center of the Vee. The left side of the Vee presents the thinking, or conceptual, basis of the study and includes the world view, theories, principles, and concepts that guided this research. These ideas helped determine the objects, events, and people that were studied and the information

that was recorded and analyzed. Methods, procedures, and research products are listed on the right side of the Vee and include value claims, knowledge claims, transformations, and records. The objects and events on which the study focused lie at the point of the Vee. A Gowin's Vee enabled the teacher-researcher to plan an inquiry with a view toward how the new knowledge would be constructed.

### **Flow Diagram of the Research**

A Flow Diagram of the Research (see Appendix B) was developed to plan an inquiry with a view of the sequence in which new knowledge was to be constructed. It includes the ongoing literature review from 1996 until the present; the ongoing development of a world view; a pilot study (spring, 1998) using the ASM CD-ROM biofilm imagebase; beginning development of a biofilm teaching module (March, 1998); script writing of the biofilm video, computer training, evaluation of student motivation (fall, 1998); filming/editing of the biofilm video, communicating with ASM and the Center for Biofilm Engineering (spring/summer, 1999); teacher training, research with high school students (spring, 2000); cross-age teaching, analysis of data (spring/summer, 2000); and, writing of dissertation (beginning in the summer, 2000).

This teacher-researcher hypothesized that learning activities designed to incorporate content and assessment standards set forth in the National Science Education Standards (NRC, 1996), Excellence in EE-Guidelines for Learning (K-12) (North American Association for Environmental Education [NAAEE], 1999), the American Association for the Advancement of Science's (AAAS) Project 2061 reform initiative (AAAS, 1989), State Department of Education Frameworks (1997), and the American Society for Microbiology Curriculum Guidelines (1998) would effectively

increase performance and motivation in science among high school female student and middle school student participants. These guidelines are strongly integrated with each other and in fact the ASM Curriculum Guidelines (1998) are not included in a separate document but refer back to the National Science Education Standards (NRC, 1996).

It was also hypothesized that when several instructional principles based on constructivism (Savery & Duffy, 1996) are used to engage female high school biology students these students develop deeper understandings of science and are more motivated to learn science. The principles that were applied in the learning environment were as follows:

- 1) The individual learning activities were tied to a larger task. The culminating activity was to adapt the biofilm image product and the instructional video to cross-age teach middle school students the selected microbiology concepts.
- 2) The teacher participants facilitated learning but the students assumed ownership of the tasks. They worked cooperatively to set goals, make decisions, share responsibilities, design and construct the biofilm image product, and communicate science with others.
- 3) The students participated in an authentic task. They entered the science domain by interpreting the images and communicating with biofilm researchers. They interpreted and adapted the images as a scientist would do.
- 4) The teacher participants set up a complex learning environment. Students learned about biofilms and microbiology in the context of ecology.
- 5) Students had ownership of the process. They worked independently and

had the freedom of choice to set their own course.

- 6) The teacher participants supported the students but also challenged them.

Teachers were observed frequently questioning the students and asking them to defend their ideas about biofilms.

- 7) Students collaborated and interacted socially. The students were observed supporting and challenging each other as they negotiated meanings. There was give and take and in most cases each group member was expected to carry her share of the responsibilities.

- 8) Students were encouraged to reflect on their experiences. The reflective thinking that is needed for deeper understanding was often observed. The student wrote their reflections in journals each day.

### **Project Summary**

This exploratory study examined three instructional strategies estimated the relative contributions to learning of the aforementioned three instructional strategies. For the purposes of this study, exploratory meant to use qualitative inquiry to venture into areas of study where little work has been done (Patton, 1990). These instructional strategies have as their underpinnings the educational theory of human constructivism, as well as selected theories drawn from cognitive science. These instructional strategies, which are based on the aforementioned science education standards, were used to create a learning environment in which students interacted through teacher facilitation of cooperative learning, peer teaching, and cross-age teaching. Video technology, a computerized imagebase, and telecommunications were used as cognitive instructional resources to facilitate learning.



The need for the proposed study is emphasized by the challenges faced by science educators today. Today's rapid technological advances and accumulation of knowledge are unprecedented making it impossible for a student to learn all of the scientific principles and concepts contained within a specific science discipline. Furthermore, a democratic society requires that its citizenry be able to make informed decisions, both personally and in the voting booth. These needs are further underscored in the literature review (NRC, 1996).

The information gathered in this study contributes to the body of knowledge on effective instructional strategies used in microbiology education (American Society for Microbiology [ASM], 1999). Though the study found no significant differences in student learning outcomes on the written pre- and posttest, the findings were mixed. The instructional strategy of accessing the biofilm images through the ASM CD-ROM and communication with biofilm researchers had some negative effects on learning. A pilot study revealed inherent flaws in the CD-ROM that prevented optimal use by the students. This, combined with the difficulty in navigating and manipulating the images into presentation format, frustrated the students more than it helped interest them in biofilms or helped them construct understandings. Positive results were observed when the students accessed the biofilm images through the ASM web page. Most students successfully adapted the images in abstract ways that increased their understanding of microbiology. Some groups however, were limited in their adaptations and only repeated the information contained in the web page. Cross-age teachers (CAT) successfully adapted the image products to teach middle school students

Communication with biofilm researchers had negative effects when the students received no response or received a response that led them nowhere or made them feel inadequate. Many students reacted positively when the communications encouraged them and helped them find information about biofilms. The lack of communication seemed at times to be the fault of the student and other times the fault of the scientist. The results offered insights into how to maximize the potential of communication with scientists. The concept of biofilms was found to engage the students and their understanding of microbiology increased.

The instructional video positively affected the students by increasing their understanding of microbiology and biofilms in particular. Some of the students responded negatively to aspects of the video and the timing of its presentation to the students. The students effectively adapted the video to cross-age teach middle school students.

Changes in motivation were difficult to measure and attempts to do so may have been outside the practical scope of this project. Motivation to study science or to select a career in science may be more dependent on long-term effects than on such a narrow intervention as this project. However, CAT teachers showed either no change or an increase in motivation.

## **REVIEW OF LITERATURE**

### **Theoretical Framework Supporting the Research**

#### **Understanding Learning**

##### **Cognitive Science**

The literature on cognitive science is extensive and it is the intent of this teacher-researcher to present only a brief overview of how it shapes learning and teaching although its principles contribute greatly to this teacher-researcher's worldview. Gardner (1985) has reviewed the cognitive revolution that began in the mid-1970s in opposition to the psychology of behaviorists such as B. F. Skinner, Edward Thorndike, and others. Noam Chomsky and George Miller presented new theories of a "science of the mind" at a 1956 MIT symposium that are credited with beginning the cognitive revolution (Bruer, 1993). One of the main contributions of cognitive science to education has been to help us understand how individuals learn and Bruer has provided a reflection on how cognitive science has moved from theory to the classroom. For example, research in the field of cognitive science indicates that teachers should teach higher order thinking skills such as reasoning and judgment, in addition to content.

Research indicates that children come to school with informal schema, or prior knowledge, that they have already developed. Schemas are associative structures that store knowledge in an individual's long-term memory about specific events, objects, or words. Individuals build new learning onto these schemas and they enable them to make inferences and predictions about objects and events that they do not actually

experience. "Thus, prior knowledge affects how we interpret school instruction and thus affects what we can learn. School instruction that ignores the influence of preexisting knowledge on learning can be highly ineffective" (Bruer, 1993, p. 28). Cognitive scientists also assert that children learn science best through activities that allow them to problem solve.

### **The Context of Learning**

Meaning making takes place in the context of the culture of the learner. Even children's beliefs about their intelligence arise within the cultural setting of the classroom and can affect their motivation. Psychologist Jerome Bruner's (1996) essays about education reveal how culture influences the mind's "meaning making" because "if pedagogy is to empower human beings to go beyond their 'native' predispositions, it must transmit the 'toolkit' the culture has developed for doing so" (Bruner, 1996, p.17). One of the tenets that Bruner proposes to guide a "psycho-cultural approach to education" is the constructivism tenet. In this context, reality is constructed using the "tool-kit" of the culture and part of the "tool-kit" includes "thinking about thinking." This awareness of how one learns is referred to as metacognition.

Other research indicated that the domains of science and everyday life have different goals and different cognitive means to achieve these goals (Reif & Larkin, 1991; Resnick, 1992). Learning problems occur because students try to use everyday cognitive skills that are inappropriate to the science domain. Classroom instruction is often inadequate because educators and students are not aware of the similarities and differences between the two domains. Teachers are mainly concerned about teaching content, but should also teach the cognitive processes used by scientists. These

cognitive processes should be taught within the science curriculum, not as a separate entity (Reif and Larkin, 1991; Resnick, 1992).

Psychologist Ellen Langer (1997) analyzed several myths about how learning takes place. These myths are embedded in commonly used instructional strategies such as rote memorization, “over learning” of skills, and being taught information from a single perspective, usually that of the teacher. Placing overemphasis on right and wrong answers, and reinforcement with rewards are other strategies that negatively affect learning. Unfortunately, these strategies are used in most classrooms today. Langer stressed that mindful learning can result when teachers refute these myths and give students the freedom to explore and experience.

Resnick (1992) examined higher order thinking skills and defined these as mental activities that enable the thinker to construct meaning, not to discover meaning that exists in the teacher's knowledge base. Construction of meaning is effortful, or therefore, requires that the thinker be motivated. Even young children can use higher order thinking skills when taught them in the context of specific science content. These higher order thinking skills are particularly important to the science of biology. The biology teacher has the added responsibility of teaching these skills so students can make decisions about the rapidly advancing technology in the field (McMurray, Beisenherz, & Thompson, 1991). Carefully chosen understandings of how students learn that are based on cognitive science informed this research and the selection of instructional strategies used in it.

### **Meaningful Learning Theory**

Meaningful learning theory was first introduced by Ausubel et al. (1978) in the early 1960s. His assimilation theory describes the process in which knowledge is assimilated into the learner's cognitive structure by adding new information to prior knowledge that the learner has already acquired. In other words it is the "nonarbitrary, nonverbatim substantive incorporation of new ideas" into a learner's cognitive structure (Mintzes et al. 1997, p. 39). When this has occurred, meaningful learning has taken place. It must be kept in mind that "the single most important factor influencing learning is what the learner already knows." (Mintzes et al. 1997, p. 39).

Ausubel distinguished between rote and meaningful learning. They are at opposite ends of a continuum with rote meaning the memorization of isolated facts. Only through meaningful learning does deeper understanding evolve. Meaningful learning is more persistent in the learner's memory structure than rote learning and represents a higher level of learning. Meaningful learning requires active participation by the learner and can be facilitated by the teacher (Ausubel et al. 1978).

Ausubel also analyzed the paths to meaningful learning and proposed a reception-discovery learning continuum. Meaningful learning can be reached through either reception learning or discovery learning. Reception learning predominates in the teacher-centered classroom where lecture is the method for delivery of information. On the opposite end of the continuum is discovery learning, where students solve a problem on their own. Somewhere in-between the two is assisted discovery learning, where the teacher offers some direction in the problem-solving process. Instructional strategies

can facilitate meaningful learning by using either approach, or any combination of reception and discovery learning (Ausubel et al. 1978).

Ausubel proposed that new concepts are linked to prior knowledge through the process of subsumption. The learner links, or subsumes, more specific concepts to general concepts that already exist in the learner's knowledge structure, resulting in a hierarchical framework. The teacher can help learners make the connection between prior knowledge and new information through the use of advance organizers such as concept maps or Vee diagrams. When meaningful learning progresses, the learner is able to further refine and elaborate on the relationships between subsumed concepts and general concepts. Ausubel refers to this process as progressive differentiation. Meaningful learning is the "bedrock" upon which knowledge is constructed (Novak, 1998).

The three instructional strategies that were used in this research focused on facilitating learning and motivation to learn. Evaluation of the records produced by participating students and teachers was used to estimate the relative contributions of these instructional strategies to student understanding and motivation. If meaningful learning occurred, the learner made connections between related concepts, thus building a cohesive cognitive structure that supports analytical thought and reasoning (Mintzes et al. 1997). The connection between meaningful learning and motivation is that people tend to enjoy doing things that they can understand and at which they are successful, and past experience is used as a predictor.

## **Human Constructivism**

### **The Many Forms of Constructivism**

The foundations for human constructivism lie in meaningful learning theory and the development of constructivism as a learning theory. Science philosopher, Kuhn, in his influential text, The Structure of Scientific Revolutions (1962) was, in effect, the first to assert that a paradigm war was occurring between positivism and constructivism. He proposed that science evolves because scientists solve problems, not because they simply test existing scientific theories. The contemporary field of education has emerged from these paradigm wars that have been fought for over 30 years, shifting from the scientific /empirical tradition to one that is more interpretive /phenomenological (Pinar et al. 1996; Tashakkori & Teddlie, 1998). This research study examined how student participants constructed meanings and identified patterns of change in students' motivation to study science.

The paradigm wars in education resulted in new learning theories, including constructivism. Constructivism, as a learning theory, has had a major influence on contemporary science and math education. It is a set of beliefs about knowing and its epistemological view is that the knower and the known are dependent. Meaning is at least partially subjective because it is not simply discovered but constructed by the individual. Constructivism opposes positivism, the prior dominant theory that claims to be objective and purely empirical.

There are many interpretations of constructivism (Geelan, 1997; Good, 1993) and critics remind supporters that there is no uniform meaning (Matthews, 1997). Though constructivism is generally considered to be a set of beliefs about knowing,



much of the debate over constructivism is over how to define its processes. Piaget, who has been credited as the “great pioneer” of constructivism (Good, Wandersee, & St. Julien, 1993) proposed that individuals construct meaning as an adaptive strategy; a sort of “genetic epistemology”. Others (Vygotsky, 1986; von Glasersfeld, 1993; and Tobin, Tippins, & Gallard, 1994) view meaning construction as the result of social interactions.

Von Glasersfeld (1993) emphasized the importance of providing students with experiences from which they can learn through social interactions. Through this interaction, students verbalize problem solving and increase their understanding by explaining events or observations to their peers. They see themselves as part of a group in which everyone has to search for answers instead of memorizing what the teacher provides as the correct answer. Students lose their fear of being embarrassed from giving a wrong answer and are free to struggle with problems.

Some authors have called constructivism an epistemology while others define it as a pedagogy. Science educators have been cautioned against using constructivism as a science method because this would

diminish its power as a set of intellectual referents for making decisions in relation to actions. Just as constructivism can be used to explain how students make sense of experience in interactive discussions or in small-group problem-solving activities, so too it can be used to explain why learning occurs in lectures and how lectures can be adapted to improve the quality of learning. (Tobin et al. 1994, p. 47)

In terms of curriculum, "the teacher would typically take account of what students know, maximize social interactions between learners so that they can negotiate

meaning and provide a variety of sensory experiences from which learning is built." (Tobin et al. 1994, p. 47). In this type of learning environment, the teacher continually interacts with the students, serving as a mediator who maximizes learning experiences and exposes students to both science content and processes. Emphasis is on the learner, not on the discipline. Teachers provide opportunities for the students to freely express their understanding through authentic assessment or alternative assessment. Judging and rewarding are de-emphasized, so that the student does not focus on pleasing the teacher, and students are encouraged to ask questions and search for answers.

### **Human Constructivism as a Model for Science Teaching**

As Good (1993) has said, "With the many versions of constructivism currently in use, we should be aware that one person's version is likely to differ from another person's version" (Good, 1993, p. 1015). In order to eliminate confusion over the meaning of constructivism it is important to state that the major theoretical influence on the current research is human constructivism, which spans the gap between learning theory and classroom practices. Human constructivists (Mintzes et al. 1997) proposed that learning only takes place when teachers and instructional strategies, appropriate conceptual knowledge, and the proper educational environment are carefully and thoughtfully integrated. Theories can and should influence practice and it is through this connection that actual science education reform can take place.

Human constructivists offer a model of science teaching in which the goal is the negotiation of meaning through social interaction while confronting natural phenomena. Human constructivists differ from radical or social constructivists such as von Glasersfeld because they emphasize cognitive processes and prior knowledge that forms

the basis of the cognitive structures upon which new knowledge is constructed. They also point out that nature is the necessary referent for explanation. This model offers a set of assumptions and guiding principles that are the underpinnings of the proposed research.

The role of the human constructivist teacher is to facilitate the negotiation of meaning while interacting with the learners. The teacher must adhere to the assumption that all learners are capable of change but they must be willing to change if the construction of meaning is to occur. Teachers "have an ethical and professional responsibility to stretch the bounds of students' knowledge within some "zone" of modifiability." (Mintzes et al. 1997, p. 50) The human constructivism model emphasizes ... "quality over quantity, meaning over memorizing, and understanding over awareness" (Mintzes et al. 1997, p. xvii).

### **Dual-Coding Theory**

Paivio's dual-coding theory (DCT) has influenced the proposed research because biofilm images from an American Society for Microbiology (ASM) digitized imagebase were chosen as an instructional design strategy. DCT examined how visual experiences enhance learning (Paivio, 1986). This theory asserts that people can and do encode ideas both verbally and visually to increase recall, and this idea is supported by empirical evidence that there are separate but linked structural and functional verbal and imagery subsystems within the mind's representational system. The imagery system processes scenes and objects, and produces mental images, while the verbal system processes language symbols. Environmental stimuli activate both verbal and imagery subsystems (encoding) through sensory perception. Because of the integration of the

verbal and visual subsystems, one may activate the other through the process of recording. Paivio has shown that there is better recall of information that is presented in pictures and graphics too, not just words. The dual coding in two memory systems seems to enhance the likelihood of recalling the information (Paivio, 1983).

## **Science Education Reform Movement**

### **The Need for Change**

The call for reform in science education in the United States has not been a single event but an ongoing discussion and debate. A Nation at Risk, the 1988 report of the NCEE, focused public attention on educational systems that were not meeting the needs of America's citizens. It stated, "For the first time in our country, the educational skills of one generation will not surpass, will not equal, will not even approach, those of their parents." (NCEE, 1983, p. 11)

More recently, United States students' performance on the Third International Mathematics and Science Study (TIMSS) (NSTA, 1998) focused more attention on the status of science education in the U.S. TIMSS compared several factors including student achievement in mathematics and science in grades 4, 8, and 12 with those of 21 other countries. Performance of U.S. fourth-grade students was above the world average, eighth-grade students was below the world average, and twelfth-grade students was significantly below the world average. U.S. twelfth graders scored last on the physics test. U.S. students performed well on recall questions and poorly on questions that required self-organization and interpretation (Aubrecht, 1999).

The issue of the inadequacies of science education has been debated. The TIMSS report sparked debate by eliciting a series of dichotomous responses (NSTA,

1998). Supporting the study was the National Science Board (NSB), established by Congress in 1950 to serve as an independent, national science policy body and to oversee the activities of the National Science Foundation. As a result of this study and a compilation of related regional data, the NSB made recommendations to improve mathematics and science literacy. It strongly asserted that U.S. students' generally low performance was partly the result of low expectations. The NSB called for a united effort of parents, educators, and the community to set the goal of producing a scientifically literate population. The nation's future will be determined by whether this is done. Other responses to the TIMSS study have been to question the validity of its findings (NSTA, 1998). In spite of the debate over the validity of the TIMSS study, there is general agreement that reform is needed.

### **Efforts to Improve Science Education**

Several innovative projects were developed in answer to the need for reform. The Scope, Sequence, and Coordination (SS&C) Project was one that emerged early in the reform movement (Aldridge, 1992). This project was based on what appeared to be serious deficiencies in the scope, sequence, and coordination of science subject matter and a need to make science education available to the student population as a whole and not just a select group. Proponents of the project provided evidence that achievement was largely measured by students' memorization of science "factoids," and not in terms of their understanding and motivation. These findings influenced the decision to focus the proposed research on students' understanding and motivation rather than on the concepts learned.

A large increase in federal spending for science education as well as state and national reformulation of policies and standards have facilitated the reform movement. The National Science Education Standards (NRC, 1996) and Project 2061's Benchmarks for Science Literacy (AAAS, 1993) are directed towards activating administrators, teachers, and the community. These documents stress the need for a concerted effort by all these groups to improve the status of science education.

These projects were in general agreement that all Americans need to be scientifically literate and can both enjoy and learn science (NRC, 1996). The goal of science literacy for all Americans was central to the reform movement, as evidenced in Bybee's review of 20 years' of reports on the issues involved in science education reform (Bybee, 1996). This goal was also partly economically driven since it would provide the nation with a more scientific and technically skilled workforce to compete in a global market.

### **Standards Based Reform**

The National Science Teachers Association recommends that the National Science Education Standards (NRC, 1996) be used to guide the efforts to achieve the goal of science literacy. The National Science Education Standards include standards for science teaching, assessment, content, science education programs, science education systems, and professional development for teachers. The standards identify what all citizens should know and they promote excellence and equity.

The American Society for Microbiology (ASM) (1998) recommended that K-12 curriculum guidelines include the National Science Education Standards, the NSTA's Decisions Based on Science (NSTA, 1997), NSTA Pathways to Science Standards

(NSTA, 1996), American Association for the Advancement of Science (AAAS) Project 2061 (1989) reform initiative, and the Eisenhower National Clearinghouse for Math and Science Education supported state standards and frameworks (Louisiana State Department of Education, 1997). Environmental education standards were developed through the support of the North American Association for Environmental Education (NAAEE, 1999). All of these state and national standards correlate with each other to a fairly high degree.

The National Science Education Standards (NRC, 1996) advocates a "cohesive" vision for science teachers and more involvement of teachers in the design and selection of curricula changes in classroom pedagogy. These changes include less emphasis on traditional teaching methods and more emphasis on a) understanding the uniqueness of each student, b) adapting curriculum, c) promoting understanding and inquiry, d) facilitating the active engagement of the students in their own learning, e) continuously assessing student understanding, and f) empowering students to take responsibility for their own learning (NSTA, 1996). Curricula should focus on depth of understanding of science principles (Rakow, 1999).

The Biological Sciences Curriculum Study (now named simply, BSCS) defined specific goals and instructional strategies for biology education that are aligned with the National Science Education Standards (BSCS, 1993). BSCS, supported by the National Science Foundation, produced Developing Biological Literacy as a curriculum framework to guide biology curriculum development at the secondary and post-secondary levels. Its specific goals for biology education include

increasing concentration on major unifying principles of biology and biological inquiry; teaching biology in contexts that have personal, social, and ethical meaning; developing active learning environments through better use of discussions, laboratories, field experiences, and educational technologies; providing implementation strategies for new programs, and improving the biological literacy of all students.

( BSCS, 1993, p. vii)

### **Implementation of the National Science Education Standards**

Science education is now in the implementation phase of reform. Major responsibility for implementation lies with the classroom teacher who must use the standards as a tool in formulating objectives, planning the curriculum, and devising teaching strategies that will effectively enable students to learn science. The National Science Education Standards (NRC, 1996) does not advocate a specific curriculum but strongly states that teachers should collaborate to develop curricula and be flexible when using them in the social context of the science classroom. Novel and defensible instructional strategies and the National Science Education Standards (NRC, 1996) used in the proposed research study because while new curricula are necessary, they are not sufficient for effective reform.

Implementation influenced by human constructivism requires that major changes be made in the traditional ways in which science has been taught. To facilitate this change professional development and teacher education should provide teachers "with opportunities to develop theoretical and practical understanding and ability"...(NRC, 1996, p. 5). The state where this research was conducted was one of



the first 10 states where the Exxon Corporation, NSTA, and science education leaders provided this type of teacher education so that teachers can more effectively implement the science education standards. Through “Building a Presence for Science,” teachers within the state served as Key Leaders to educate teachers as Points of Contact (POC) within individual schools. These POCs then educated their colleagues in the standards. The high school biology teachers who participated in this research have been educated in the standards.

### **Scientific Literacy: The Goal of Science Education**

An understanding of what scientific literacy encompasses is central to this research. Scientific literacy is a term that was first used in the 1950s and that became a slogan for educational efforts to provide the business and technology community with skilled workers. There is no consensus of a definition of scientific literacy (AAAS, 1993; Bybee, 1996; NRC, 1996); however, there are some common features (Mitman, Mergendoller, Marchman, & Packer, 1987). These include building students' understanding of the nature of science; science concepts; interrelationships between science, individuals, and society; ethics of science; science and technology; and historical perspectives of science. Marlow and Marlow (1996) define scientific literacy in terms of what science includes: products, processes, and values. Products represent the conceptual information and knowledge of the nature of science. Processes include the mental skills needed to problem solve and conduct investigations. Values encompass the attitudes and beliefs of science that determine the methods by which science is performed.

BSCS (Bybee, 1996) described the levels of scientific literacy, or dimensions, that must be understood by students. They include nominal, functional, conceptual and procedural, and multidimensional levels of scientific literacy. The highest goal of science education is that every American student achieve multidimensional scientific literacy. Biological literacy may be considered as a subcategory of scientific literacy. BSCS emphasized the need for students to achieve the multidimensional level of biological literacy (BSCS, 1993).

At the lowest level of understanding, or nominal scientific literacy, individuals would be able to identify scientific terms as being a part of science. However, they would have many misconceptions of science based on incorrect prior knowledge and would lack the ability to explain scientific phenomena adequately. At the functional level, they would be able to provide memorized definitions of scientific terms. Their understanding of biology is greater at the conceptual and procedural level. At the multidimensional level students would be able to understand the uniqueness of science, know its history and nature, and understand its social context. Students who have a balance of each level have achieved scientific literacy (BSCS, 1993).

### **Underlying the Selection of Instructional Strategies**

#### **Motivation and Gender in Science**

The selection of strategies was guided by the need to motivate female high school students in science. A secondary goal of the research was to observe any resulting changes in motivation to study science by the student participants. Motivation to complete a task can be observed in the student-centered classroom. Hannafin and associates (1996) reported that in computer based instructional environments motivation

is needed in order to keep students on task. Because students in this study used computer technology to access the images the relative amount of time spent focusing on the biofilm imagebase might indicate motivation. Students are often motivated when the activity itself rewards them and maintains their participation in the activity. When students return to an activity without being rewarded by external motivators such as teacher's comments or grades they exhibit continuing motivation. Direct observation enabled the teacher-researcher to observe any immediate changes in motivation resulting from the instructional activities.

It may be more difficult to estimate changes in long-term motivation to learn science. It is difficult to distinguish student interest in a specific subject from motivation, as reported by Tobias (1994). Interest was found to stimulate motivation and external motivators, such as rewards, stimulated interest. The study was originally designed to assess student changes in career interests as recorded on the career interest indicator section of the PLAN test (ACT™, 1998). The PLAN is a preliminary ACT™ assessment test that is taken by sophomore high school students to predict their scores on the ACT™ Assessment. The ACT™, taken during the junior and senior years, is used to assess students' ability to complete college-level work. Many colleges use the results on the ACT™ in their college entrance selection process. Initially student responses on the career interest indicator portion of the ACT™ PLAN test taken prior to the ecology unit were to be compared to responses made one month after completion of the unit to estimate any changes in motivation in science. Consultation with an ACT™ statistician revealed that the career interest indicator items are intended to tap broad every day experiences and would not detect changes due to narrow intervention such as

these teaching strategies. At his recommendation it was decided to ask selected students who were interviewed to self report any perceived changes in motivation in learning science.

The selected female high school biology students in the study represented a sample of convenience and "female" is only a descriptor of the population. Knowledge of gender differences in science motivation may be important. Gender differences in American culture have been analyzed quite extensively. The historical record reveals that limited educational opportunities and lowered expectations for women (Davis and Rimm, 1989) have affected the role of women in American society. Grumet, Miller, Mitrano, Wallenstein, Pagano, and other curriculum theorists have stimulated intellectual dialogue on gender and the curriculum (Pinar et al. 1996).

Data from the National Assessment of Educational Progress (NAEP) 1996 long-term trends in science performance show mixed results for males and females since its first assessment in 1970 (National Assessment of Educational Progress [NAEP], 1998). All three age groups studied, 9-, 13-, and 17-year-olds, showed scores that fell and then rose. However, 9- and 13-year-olds showed an overall increase and 17-year-olds a decline. Both 13- and 17-year old male students had higher scores than their female counterparts but the differences in scores for 17-year-olds declined.

Other researchers have examined why girls underachieve in school and in science classrooms in particular. Kahle (1992) cited the classroom environment as the major factor in educational underachievement of girls. Girls have demonstrated less experience with the tools and equipment of science. In addition, girls score lower than

boys on the math and science sections of many standardized achievement tests (Kahle, 1992).

The American Association of University Women's 1998 Gender Gaps Executive Summary documents 1000 research studies on gender equity in schools since 1992. It shows that the number of science courses that girls take has increased but boys are still more likely to take the three core courses – biology, chemistry, and physics. Girls still pursue fewer career options than boys do and only 6 percent of women are in nontraditional careers. Personal experience has found, in spite of a lack of recorded data on graduates of Millville Academy, the number that pursue science related careers has increased greatly and almost 90% take physics while 100% take biology and chemistry.

Potter and Rosser (1992) reviewed the research and found that the reluctance of girls to study science is often due to their low self-concept and lack of interest. Engaging girls in science activities that are relevant to their daily lives and allowing them to explore and create meanings were helpful. Their examination of sexism in seventh-grade life science text books found that subtle forms of sexism were evident. A study of girls and boys in grades 4 - 10 indicated that progress toward equity has been made. There were no gender differences in participation and though girls were less likely to see science as male-dominated, they were less likely to think science is fun and to be interested in a science career (Collier, Spokane, & Bazler, 1998).

The under representation of women in science has been attributed to cultural, educational, and personal factors. For example, parents, teachers, and guidance counselors often dissuade girls from going into science careers. The National Research

Council recommended that teaching strategies at all grade levels encourage the active involvement of girls (NRC, 1990).

### **General Standards Based Instructional Strategies**

#### **A Cooperative Learning Environment**

The National Science Education Standards (NRC, 1996) guided the selection of instructional strategies. This project established a learning environment where students worked cooperatively to construct understanding. This learning environment was informed by the large volume of research on collaborative, or cooperative learning, that provides evidence that this instructional method can be effectively used to enhance learning (Brown, 1994; Meloth & Deering, 1994; Swing and Peterson, 1982). Cooperation is natural to man, both culturally and biologically. However, the subculture of American schools has historically isolated students from students, students from teachers, and teachers from teachers. In a cooperative learning environment, individuals work together towards a common goal. That common goal is to maximize the learning of all individuals in the group (Johnson & Johnson, 1996).

Johnson and Johnson (1991) examined individualistic, cooperative, and competitive instructional strategies commonly used by teachers. They found an effective teacher to be one who used all three and knew how and when to best use each one. Competitive and individualist learning have dominated American education for the past 45 years but cooperative learning, though the most effective, is actually the least used. Through cooperative learning students have been shown to learn better, like school better, to have a higher sense of self-efficacy, and develop effective social skills (Johnson & Johnson, 1991). Cooperative learning in the science classroom was found

to foster greater mastery and retention of content. Cooperative learning also fostered more positive attitudes among the participating students (Humphreys, Johnson & Johnson, 1978). On the other hand, Johnson and Johnson (1996) also found traits that inhibit cooperative group performance including “social loafing”, “free riding”, not being a “sucker”, groupthink, insufficient heterogeneity, lack of teamwork skills, inappropriate group size, uncritical acceptance of members' dominant response, and lack of group maturity. Strong teaching skills are needed to counteract these traits.

Brown's Community of Learners Project (1994) employed collaboration between students and teacher to enhance learning. Setting up a learning environment much like a research community encourages the students to become experts on a sub concept and then jigsaw together to form higher level concepts. This situational learning also extends outside the classroom through electronic communication. Brown also believes that the goal of educational research should be to use learning theories to develop instructional strategies that will enhance learning.

Research studies on cooperative learning in biology also demonstrated increased student achievement and understanding when compared to more traditional teaching methods (Lord, 1998). Comparisons of teacher attitudes before and after training in cooperative learning demonstrated a positive effect. In spite of the evidence in support of cooperative learning, many biology teachers continue to use traditional methods of recitation and rote memorization in teacher directed classrooms. Recommendations for effective cooperative learning activities in the biology classroom have been made and compared with ineffective cooperative learning activities (Lord, 1998). Watson (1991)

found an additive effect when students were grouped, groups worked on group tasks (Group Educational Modules), and the groups were structured heterogeneously.

### **Computer-Assisted Cooperative Learning**

Today's learning must prepare students for the 21<sup>st</sup> century in which new technology and access to information are increasing at an unprecedented rate. Many science teachers may be inadequately prepared to successfully integrate computer technology in the classroom. Technology-assisted cooperative learning was reviewed extensively by Johnson and Johnson (1996). Educational computer software has largely been marketed for individual use and there is some evidence that this decreases its effectiveness as an instructional tool. Johnson and Johnson (1996) listed three factors of individualized instruction that limit its potential use, two of which are relevant to this research. They included the following: a) students who work individually over long periods of time on a computer may seem less motivated, and b) students are not able to tap into the resources provided by other members of cooperative groups. These human resources include cognitive and social benefits associated with group interaction, such as encouragement, support, and increased ability to process mental images.

Johnson and Johnson (1996) were involved in several studies of academic achievement of students in computer-assisted cooperative learning. Students from eighth grade through college freshmen performed tasks using word processing and problem solving. When compared with competitive and individualistic learners, these students had higher quantity and higher quality of daily achievement. There are mixed data regarding gender effects of computer-assisted cooperative learning but, generally, no major performance differences were found.



Research indicates that teachers must plan and manage cooperative groups for more effective learning. There is disagreement over whether homogeneous or heterogeneous groups are more effective. Johnson and Johnson (1998) found that in heterogeneous groups high achieving students benefit from giving explanations to their peers and lower achieving students benefit from the assistance of the high achieving students. Others have found heterogeneous grouping to be less beneficial to high-achieving students (Johnson & Johnson, 1998). This study supports heterogeneous grouping based on Slavin's (Doran, Chan, & Tamir, 1998) criteria because it was predicted that it would be more beneficial to the students but only if the teachers closely monitored the groups.

### **Computer and Video Technology as "Thinking and Learning" Tools**

#### **Can Computer Use Benefit Learning?**

This research examined how computer and video technology can be used in novel ways as cognitive tools as opposed to using them to improve what we were already doing, for example, learning the same information but in a faster way. There has been some debate about the benefits to learning that technology can offer and much of this may result from how it is used. As an example, Clark (1983) asserted that computer technology can be used as a tool for delivering instruction but does not increase achievement. It is the assumption of this teacher-researcher that it is too soon to make assertions of this nature because computer technology and its use have advanced too rapidly. Much more data need to be compiled and analyzed under a variety of learning conditions before logical assertions can be made.

Relevant to the proposed research, an in-depth case study of teachers' use of image processing in biology, earth science, and physics classes within one high school examined issues involved with implementation of image processing. It identified factors that determined whether or not teachers used computer technology for image processing. Teachers' decisions were based on factors including a) teachers' computer use outside the classroom, b) teachers' attitudes toward and experience with educational technology, c) training and perceived influence of administrators, and d) ability to implement inquiry-based learning activities (with or without computer technology). This study found that implementation was not synonymous with effective science teaching and that some teachers did not use computer technology because they did not connect it to teaching science. The researchers concluded that the fundamental reason for computer technology use should be to enhance student-centered, inquiry-based science learning. (Greenberg, Raphael, Keller, & Tobias, 1998). Others have agreed that computer technology is a tool that is only useful if thoughtful decisions are made about how it should be used (Burnes, 1997).

### **Teacher Perceptions**

A national survey on the use of computer technology revealed that teachers have conflicting perceptions of how constructivist instructional strategies can be used to implement science education reform (Ravitz, Wong, & Becker, 1998). The survey found that the constructivist practice of having students make a product and demonstrate their work to an outside audience was done less in academic subjects than in nonacademic ones such as vocational education. However, this study made the assumption that projects are meaningful tasks that integrate knowledge and skills and

extend learning and computers can facilitate this meaning making. Computer technology such as databases and composition software can also be used to engage students in science learning tasks that require higher order thinking skills. Students are able to access a variety of information and communicate with others outside the classroom when constructing their own understanding. Generally, teachers who perceived themselves as constructivist used computer technology as an instructional tool more than more traditional teachers. (Ravitz, Wong, & Becker, 1998).

There is strong agreement that computer technology and computer technology-enhanced programs engage students in learning. Several classroom variables have been reported to be good indicators of student engagement in learning:

a) children are engaged in authentic and multidisciplinary tasks, b) assessments are based on students' performance of real tasks, c) students participate in interactive modes of instruction, d) students work collaboratively, e) students are grouped heterogeneously, f) the teacher is a facilitator in learning, and g) students learn through exploration" (Jones, Valdez, Nowakowski, & Rasmussen, 1996, p. 7)

Other reports indicate that computers used as cognitive tools support reflective thinking and mindful learning only if the learner is mindfully engaged in the learning task. Learner control can engage the learner and is another aspect of computer technology use that affects learning. The learner can regulate the pace at which information is presented, the sequence of presentation, and can even determine the content (Duffy & Cunningham, 1996). It was reported that learner control increased efficacy and achievement. However, learners sometimes misjudged their information

needs and sought unnecessary information or left out important information (Hannafin, Hannafin, Hooper, Rieber, & Kini, 1996). Other innovative approaches to technology assisted learning included student creation of multimedia presentations to deliver instruction (Weller, 1996).

### **Instructional Strategies Specific to this Research**

#### **Novel Use of Biofilms as a Core Concept**

The primary goal of this project was to learn more about how selected female high school students developed understandings of microbiology concepts during a unit on ecology as a broad science discipline centered on the core concept of biofilms. A second goal was to observe any changes in motivation that resulted. From a human constructivist perspective, students construct better understandings when science concepts are relevant to them and their lives. Microbiology is relevant to students in many ways (Brock, Madigan, Martinko, & Parker, 1994) including the impact of microbes on their health, their environment, and even their existence. Because microorganisms are mostly invisible and the general public has little knowledge of biofilms students are not aware of their relevance. Living things as we know them could not even exist on Earth without microbes. Their negative influence on us including the potential for germ warfare and emerging viral diseases can be contrasted with their positive influence when they are used to clean up pollution and mass produce life saving drugs. Students of today need to have microbial literacy (ASM, 1998). Often microbiology is overlooked because of a teacher's erroneous perception that teaching about microbes involves a high level of expertise, complicated lab activities, expensive equipment, and more time.

Science education literature documents the many ways in which educators have made biology relevant to students. In fact, biology emerged as a science discipline nearly a century ago out of the need for the average person to be able to understand and make decisions about issues that directly affect her/him such as conservation and health (Lung, 1999).

It is often a challenge for teachers to make science relevant and meaningful to students. "Scientific topics that have been highlighted by current events provide one source, whereas actual science-and-technology-related problems provide another source of meaningful investigations" (NRC, 1996, p. 173). The topic of biofilms meets these criteria because it represents innovations in microbiology and cutting edge scientific research. Biofilms offer ideal models of biology concepts and processes (BSCS, 1993).

### **Biofilms: A Different Way of Looking at Microbes**

#### **Ecological Communities**

Biofilms are complex communities of different species of microorganisms that grow on surfaces (substrates) in aqueous environments. A significant characteristic of biofilms is that the microorganisms produce a slimy, glue-like polysaccharide that attaches them to the surface. Biofilms usually include bacteria, algae, fungi, and protozoa. Sometimes even invertebrates such as insects are found living with the biofilm (Brock, 1994). For the purposes of this research, bacteria may be defined as all prokaryotes, or cells that lack a well-defined nucleus and other membrane-bound organelles. However, if one uses the term bacteria in its strictest sense, from a phylogenetic (evolutionary) standpoint, they are one of the two prokaryotic domains (Brock et al. 1994). The topic of biofilms is one of the most exciting in microbiology

today and it is one that can be included in meeting each of the content standards. It also has the benefit of being relevant to students' lives because biofilms affect students in many ways that they are not aware of.

Since the time of Louis Pasteur, scientists have typically studied free-floating, or planktonic, bacteria grown in laboratory cultures (Costerton & Lewandowski, 1997). The discovery of biofilms and improvements in the technology used to study bacteria have changed this. Leeuwenhoek may have been the first to observe a biofilm as he examined scrapings from his teeth under the microscope (Slackin, 1979). In the mid 1960s researchers found that bacteria in the mouth could synthesize a sticky substance that attached them to the teeth and gums. But it was not until later that biofilms were recognized as being ubiquitous and often having adverse effects on humans. In 1978, Costerton and others published an article in Scientific American that placed biofilms on the cutting edge of microbiological research. Research interest in biofilms has grown greatly since then as evidenced by the scientific literature. Costerton now heads up the Center for Biofilm Engineering at Montana State University in Bozeman, Montana, which is one of several research institutions worldwide that studies biofilms (Costerton & Lappin-Scott, 1989; Costerton & Lewandowski, 1997).

Biofilms have their own unique defenses and communication systems, and probably evolved as an adaptive strategy for survival. They form when planktonic, or free-floating, bacteria anchor themselves to surfaces in aqueous environments and begin to synthesize a slimy polysaccharide, or complex carbohydrate, that glues the individual cells together and to the surface. Biofilms are found primarily on inert surfaces such as particles of soil, plastics, metals, and medical implant devices, but can also be found on

living tissues. It is estimated that 99% of all bacteria found in open ecosystems are biofilms stuck to surfaces (Flannery, 1997; Massol-Dveya, Whallon, Hicke, & Tiedje, 1994).

They grow best on surfaces emerged in flowing water which provides a constant supply of nutrients. Adhesion, or sticking, to the surface is their adaptation to the physical action of the flowing water which could easily displace them. As the biofilm grows, layers form supporting the more aerobic bacteria (which require oxygen) at the surface and obligately anaerobic bacteria deeper within. These deeper species cannot live with oxygen. Channels form throughout the biofilm and as the water, or other liquid, flows through them it carries nutrients down into the biofilm. It has been predicted that almost all types of bacteria will form biofilms under certain conditions such as starvation. Though individual cells are invisible, this entire microcosm (the biofilm layer) can be seen with the naked eye as a slimy film (Costerton & Lappin-Scott, 1989; Potera, 1996).

### **Relevant to Human Beings**

One reason that biofilms are being studied is because of their effects on other living things and the environment. Some of these effects are detrimental but others are beneficial. Some harmful biofilms can corrode materials such as pipes and ship hulls, while others cause disease and sometimes death. The economic cost to industry, medicine, dentistry, and society is significant. Some beneficial biofilms are being used in the bioremediation of toxic wastes, oil spills, and sugar cane waste. Others are used in waste-water treatment (Day, Day, & Day, 1995). Many biofilms abound in the human body's natural flora in locations such as the large intestine where they help

remove undigested nutrient molecules and produce vitamins as products of their metabolism. Still others play an important role in larger ecosystems, including those living in marine, fresh water, and soil environments, as part of natural food chains. Predators such as protozoans feed upon the bacteria within environmental biofilms. Biofilms also assist other organisms by recycling nutrients such as nitrogen and carbon (Anderson & Hairston, 1999).

Historically, most research in microbiology has been conducted on free-floating, planktonic cells grown as pure monocultures. Today microorganisms are often studied in their natural environment attached as biofilms to a substrate. Major motivating factors that caused the focus to change were the deaths of 100 asthmatics in the U.S. in 1994. Deadly biofilms were found to be growing on the same albuterol inhalant that all of the infected asthmatics used (Potera, 1996). Although the albuterol processing plant treated its tanks with biocides, or chemicals that kill bacteria, the biofilms were resistant to these chemicals. Another widely publicized outbreak, resulted in the deaths of 29 American Legionnaires attending a convention at a hotel in Philadelphia in 1976. *Legionella pneumophila* found in the lungs of those infected may have broken loose from biofilms in the air conditioning system of the hotel. Biofilms have also been found on medical implants and prosthetic devices such as contact lenses, cardiac pacemakers, heart valves, artificial hips, and urinary catheters causing serious problems for medicine and industry (Costerton and Lappin-Scott, 1989). They are evident in diseases such as tuberculosis, cystic fibrosis, periodontal disease, and dental plaque (Potera, 1999). The Center for Disease Control and Prevention, or CDC, estimates that 65% of all human bacterial infections are caused by biofilms (Potera, 1999).



Biofilms are particularly hard to control because they are resistant to traditional antimicrobial agents such as antibiotics. Much of the research on biofilms focuses on the development of new therapeutic agents (Geesey, Characklis, and Costerton, 1989; Costerton and Lappin-Scott, 1995; and Costerton, Stewart, & Greenberg, 1999). Planktonic forms of bacteria are more susceptible to antibiotics and some researchers are concentrating on methods to prevent biofilm adhesion, or sticking (Marshall, 1992). Biofilms also resist treatment with chlorine, some disinfectants, and other biocides.

### **Cutting Edge Biofilm Research**

The newest research directed towards destroying biofilms is in the area of molecular biology and genetics. For example, it has been found that planktonic *Pseudomonas aeruginosa* cells signal each other to begin to adhere and the genes that regulate these chemical signals, or acylhomoserine lactones, have been isolated (Davies & Geesey, 1995; Davies, Parsek, Pearson, Iglewski, Costerton, & Greenberg, 1998). Using reporter gene technology, researchers found *P. aeruginosa* expressed the alginate promoter only while in the biofilm state (Davies, Chakrabarty, & Geesey, 1993). This evidence of separate phenotypes for planktonic and biofilm states may be the key to controlling biofilms.

Microbial biofilms are representative of the biodiversity, or large variety of species on Earth. Destroying biofilms could disrupt this biodiversity and one of the most controversial uses of biofilms involved taking them from their natural environment, the hot springs of Yellowstone National Park (McMillion, 1999). A federal judge ruled that the park participated in an illegal microbe deal called bioprospecting when it contracted with a private company to allow the company to

remove the organism from the park. This ruling makes the selling of microbes from the park illegal.

The pharmaceutical company removed the thermophile, *Thermus aquaticus*, from its hot springs habitat and later developed a biotechnology worth over \$100 million a year. *T. aquaticus* is used to synthesize the *Taq* polymerase enzyme used in the Polymerase Chain Reaction (PCR) to amplify deoxyribonucleic acid (DNA). This enzyme has revolutionized molecular biology.

*Thermus aquaticus* is only one example of the variety of species that live in the extreme environment of Yellowstone's hot springs. The biofilms that grow in Yellowstone consist of bacteria and other organisms that grow in extreme environments of high temperatures (above 60 - 62°C) and low pH (Brock, 1994).

The Center for Biofilm Engineering at Montana State University conducts "industrially relevant research to address these biofilm issues: biocorrosion, oil field souring, water quality, biofouling, biobarriers, and surface interactions on medical implants." (Center for Biofilm Engineering, 1999) Biofilm engineering investigators have varied areas of research interest including molecular and cellular interactions at surfaces, response of bacteria to environmental stresses, water and wastewater microbiology, biofilm control with antimicrobial agents, and gene expression of surface associated bacteria. Founded in 1990, the Center has been funded for 11 years by the National Science Foundation (NSF) with matching funds from the state of Montana. The Center is an educational and research center that focuses on understanding, controlling, and exploiting biofilm processes. Recent successes have been in the areas

of bioremediation, industrial and drinking water treatment, antimicrobials, and the genetics of biofilm adhesion.

### **Real World Problems**

Biofilms present real world problems that are relevant to students and can be used in context to develop problem-solving skills. New understandings of biofilms have changed the way scientists study them and a new interdisciplinary approach offers great promise (Geesey, Characklis, and Costerton, 1989). The Center provides practical experience for students at the undergraduate, masters, and doctoral level and has formed partnerships with industry to address real world problems. The Center's worldwide reputation in the field of biofilm research is largely based on interdisciplinary, collaborative research. This large-scale collaborative effort in scientific research offers students a model of real world situations that can integrate problem solving and cooperative group work in the classroom. Communication with scientists at the Center might close the gap between the cutting edge of science and the classroom, and biofilms offer ideal models of current biology concepts and processes (BSCS, 1993). This research consisted of activities centered on biofilms that engaged students in real world problem solving and facilitated meaningful learning.

### **Communicating Science with Biofilm Researchers**

Communication is critical to shared meaning in a human constructivist environment. This research utilized communication in a socio-cultural setting (the context of the learning environment) both within the classroom and beyond the classroom. Communication occurred between learners and peers, learners and teacher, learners and those they taught, and learners and scientists. The research began with the

assumption that "communication is a product of social relationships." (Krendl, Ware, Reid, & Warren, 1996, p. 103). Throughout the research the context included communication and interactions within the learning environment and at times the learners were the senders of information and, at other times, the receivers.

An important component of the instructional strategies was communicating science. Students had to communicate science with their teachers, peers, middle school students, and scientists. Morrison and Collins (1996) reviewed research in "what it means 'to talk' science within the classroom and among scientists "and how science dialogue can help students learn science. They refer to ways of constructing both general and domain-specific knowledge as epistemic games. The complexity of our culture impacts how students will be able to communicate "across epistemic divides". Those who have "epistemic fluency" can send and receive information in ways that enhance understanding.

There is a lack of research that investigates how E-mail communications with scientists can help students construct understandings of science. ASM has the goal of increasing public understanding of microbiology (1998). To accomplish this goal it has produced a CD-ROM (1996) and two web pages (1999) that provide images and information for teachers and students. These are examined more thoroughly in the Methods section. This study provides much needed insight into how this interactive communication can operate successfully.

### **Instructional Videocassettes**

Instructional videocassettes integrate sound and moving pictures and offer rich environments for learning. In traditional instructional strategies videos were played to a

passive student audience. Use of the video in this way would not be considered constructivist. Human constructivist strategies use videocassettes in novel ways and there is interaction between the teacher, learner, and video program.

Videocassettes facilitate distance learning where the learner and instructor are separated by time and space (McIssac & Guanawardena, 1996). A major advantage is that the instructor/learner can exercise control by using the start/view function when pausing to discuss material. The instructor /learner has control because of the stop, rewind, replay, and fast-forward features. Students can personally interact with the material and gain mastery because they have time to reflect on, analyze, and discuss the information. The student sometimes has the added advantage of being able to select the time of viewing. Video programs may be supplemented by other media that the teacher/learner may interact with such as written texts and discussion groups.

### **Cross-Age Teaching**

In this research, peer or cross-age teaching was distinguishable from tutoring in that teaching involved the presentation of new material. Tutoring usually refers to individual instruction on material already presented (Ponzio & Petersen, 1997). They supported previous research that indicated cross-age tutoring enhances learning.

During cooperative learning, peers taught within their groups through discussions in which they provided explanations (Meloth & Deering, 1994). Selected female, high school biology students also taught their peers as they became experts on sub concepts and made presentations to the class. Then through dialogic activities, including the presentations and questioning, the sub concepts began to jigsaw together to form the broader concept of biofilms (Brown, 1994) in the unit on ecology.

Cross-age teaching occurred in this research when 12 selected female, high school biology students taught middle school students. The focus of the cross-age teaching was on the contribution of this instructional strategy to the high school students' understanding and motivation to study science and not on the middle school students. Cross-age teaching has not been studied as much as cross-age tutoring and not in the context of female biology students introducing or teaching microbiology concepts to middle school students. The main difference between tutoring and teaching is that students who tutor younger students re-teach and/or reinforce concepts.

A study in which sixth-grade students taught first-grade students about plants found that both groups of students benefited from the learning experience (Smith & Burrichter, 1993). Cross-age teaching has also been studied by observing cross-grade students within an elementary school constructing projects together (Haluska and Gillen, 1995). However, in the current study the actual teaching that took place was more structured than when students learn from each other through cooperative problem solving. In a study in which eighth-grade students were given control over the strategies and materials they used to teach science to second-grade students it was found that the eighth-grade students were both effective teachers and learners (Corlett, 1998). Few studies of the cross-age teaching of middle school students by high school students in a formal educational have been completed. However, in one case high school students who taught science to elementary school students using an inquiry-centered approach were also found to be effective teachers (Lunetta & Rago, 1974). In informal educational settings such as after school community based programs, indications are

that the older students need an older adult to work closely with them and provide training and support (Lee, Murdock, & Paterson, 1996).

### **Summary**

This research was grounded in the aforementioned learning theories. The learning environment and the teaching strategies were purposely chosen with the goal of putting theory into practice as human constructivism attempts to do. The teacher-researcher's prior knowledge of how learners learn (cognitive science) and how more meaningful learning is achieved informed the interpretations made about how the students learned. Linn (1987), reporting on a planning conference on research and science education stressed the need to modify traditional approaches and establish new priorities. She asserted that researchers should plan science education research according to the present knowledge of cognition and how students construct understanding. This includes investigating new teaching strategies. Knowledge that is gained through science education research in this area will benefit students and teachers of science. Linn's beliefs are shared by this teacher-researcher and explain why the proposed research focuses on instructional strategies and understanding.

The teaching strategies and their use were purposely designed to utilize both visual and verbal cognitive structures as supported by dual coding theory. The novel use of biofilms as a core concept took students to the cutting edge of microbiology. The relevancy of biofilms to the students' lives was revealed as they experienced the instructional video, communication with biofilm researchers, and biofilm images accessed through the computer. The students collaborated to reinforce concepts, make connections between them, and construct understandings as they taught their peers and

middle school students. Learning under the best conditions was observed and evaluated for its relative success. Strong support for this type of research in science education comes from what has been learned from the science education reform effort and research on gender and science education.

### **How the Instructional Strategies Contributed to Student Understanding and Motivation**

Though the study found no significant differences in student learning outcomes on the written pre- and posttest learning did occur. Figure 1 provides an overview of the study that summarizes its components. The instructional strategies are highlighted and include a) biofilms as a concept and communication with biofilm researchers (E-mail), b) adaptation of the instructional video, and c) cross-age teaching. The instructional strategy of accessing the biofilm images through the ASM CD-ROM and communication with biofilm researchers had some negative effects on learning. The pilot study revealed inherent flaws in the CD-ROM that prevented optimal use by the students. This combined with the difficulty in navigating and manipulating the images into presentation format frustrated the students more than it helped interest them in biofilms or helped them construct understandings. In contrast, positive results were observed when the students accessed the biofilm images through the ASM web page. Most students successfully adapted the images in abstract ways that increased their understanding of microbiology. Some groups however, were limited in their adaptations and only repeated the information contained in the web page. The concept of biofilms was found to engage the students and their understanding of microbiology increased.



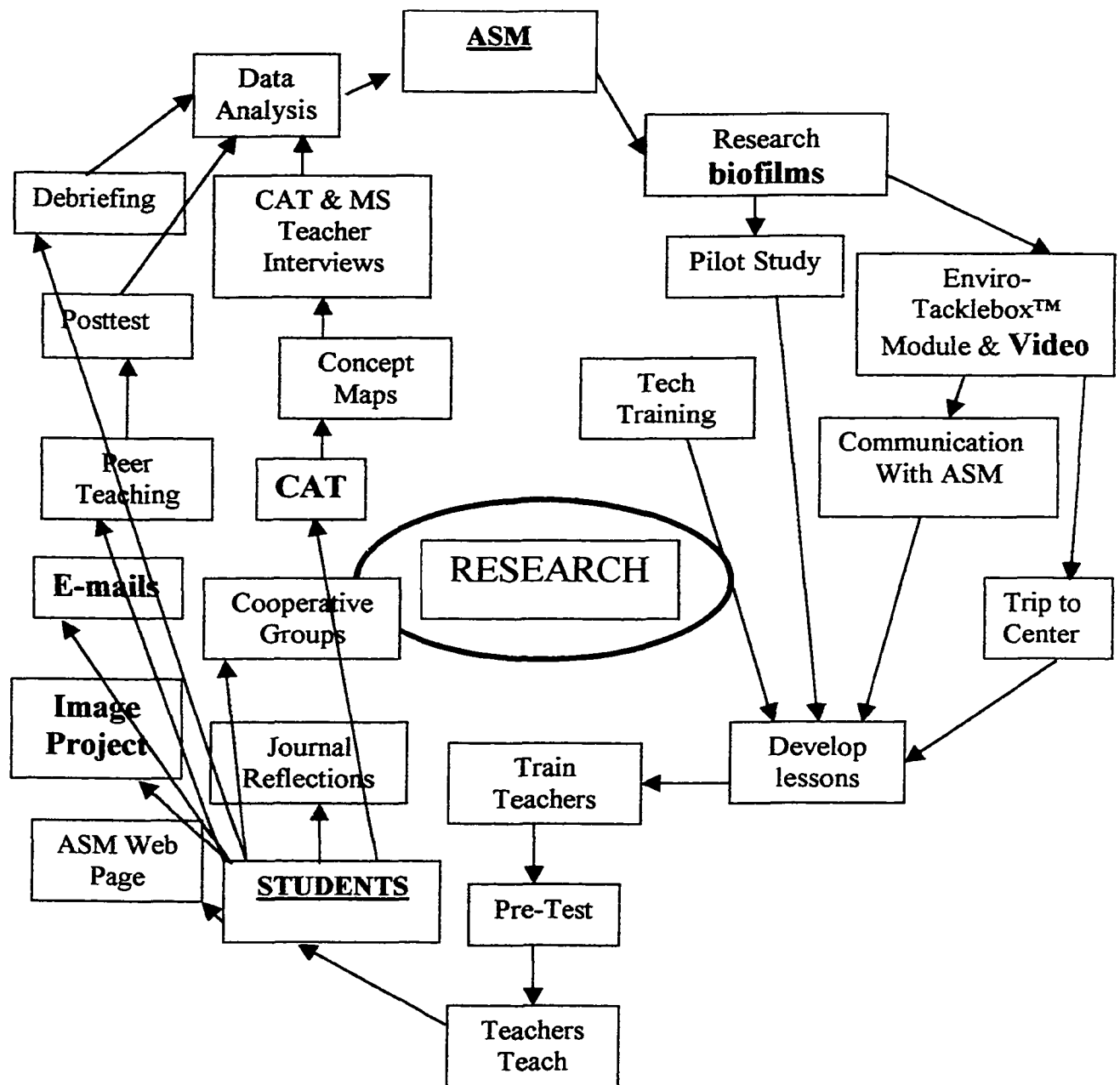


Figure 1. Overview of research study

Communication with biofilm researchers had negative effects when the students received no response or received a response that led them nowhere or made them feel

inadequate. Many students reacted positively when the communications encouraged them and helped them find information about biofilms. The lack of communication seemed at times to be the fault of the student and other times the fault of the scientist. The results offered insights into how to maximize the potential of communication with scientists.

The instructional video positively affected the students by increasing their understanding of microbiology and biofilms in particular. Some of the students responded negatively to aspects of the video and the timing of its presentation to the students. The students effectively adapted the video to cross-age teach middle school students. Cross-age teachers (CAT) also successfully adapted the image products to teach middle school students

Changes in motivation were difficult to measure and attempts to do so may have been outside the practical scope of this project. Motivation to study science or to select a career in science may be more dependent on long-term effects than on such a narrow intervention as this project. However, CAT teachers showed either no change or an increase in motivation.

### **Broader Vision**

The broader vision of this study was to offer encouragement and support for high school biology teachers to include microbiology concepts in their courses. ASM developed its CD-ROM and web page biofilm imagebase to “enable pre-college and undergraduate educators to expose their students to images that they do not have the ability to generate in their own labs, in an effort to utilize microorganisms as important vehicles for teaching major life science concepts” (ASM, 1996). The Biofilms Project

was also part of a larger effort to “use microbiology more extensively as a vehicle for teaching elementary and secondary school students about the sciences” (ASM, 1996).

Figure 2 summarizes the three instructional strategies and how qualitative data was collected and triangulated as the strategies were developed (left side) and students developed understandings of biofilms and selected microbiology concepts (right side). The relationships between data sources and instructional strategies form a complex system with teacher-researcher involvement in both input and output. These relationships reveal the dynamics of the learning processes as they occurred over time in contrast to the written pre- and posttests that captured snapshots of the beginning and end.

In this exploratory study, content analysis of the data collected from the direct observation of people, events, and objects yielded information that merits further investigation. The guidelines of qualitative inquiry (Patton, 1990) were used to investigate an area where little is known; the combined use of these instructional strategies. Qualitative inquiry is particularly appropriate in studying process. In this study, the process of how the three instructional strategies contributed to understanding and motivation. Triangulation of the data helped to confirm patterns that emerged. Understanding these patterns can help solve real problems and lead to improvements in science education. To support this exploratory study, the patterns that emerged need to be examined more thoroughly to confirm them and provide deeper understandings.

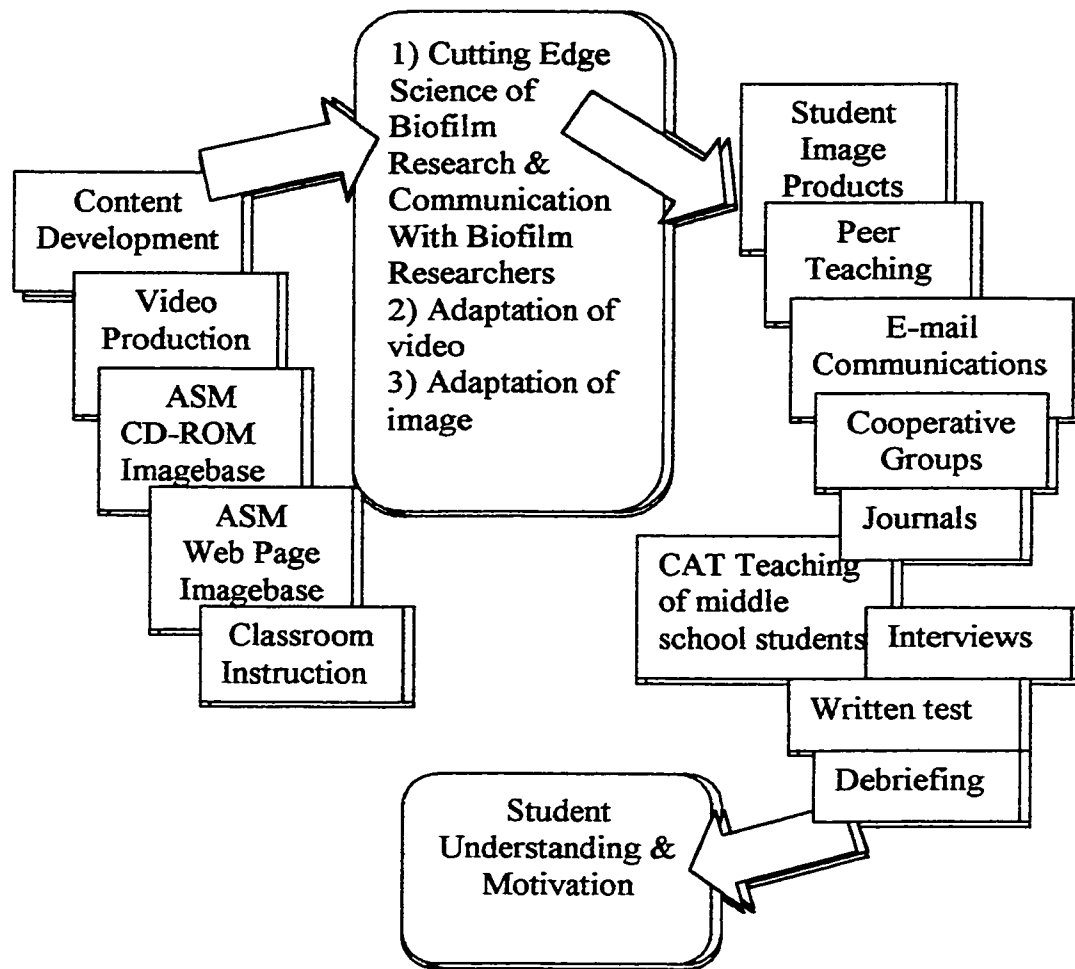


Figure 2. Triangulation of qualitative data sources

The qualitative approach that was used was open-ended with the teacher-researcher making every attempt to remain unbiased and open to patterns that emerged. It began with the teacher-researcher not knowing which strategies would be effective or how the students would use them to develop understandings. The teacher-researcher focused on what was happening as the students progressed through the unit and judgment was reserved until the analysis.

## **METHODS**

### **Research Design in Science Education Research**

#### **Qualitative or Quantitative Approach?**

Given the fact that either qualitative or quantitative methods used alone or in combination have been successfully applied to educational research a fundamental decision that needed to be made was what methods would best address the research question. The influence of human constructivism on this teacher-researcher dictated that the research design focus on the study of "multiple social realities" (Gall, Borg, & Gall, 1996). These are the many different realities that individuals construct as they interact in a social setting. This type of study can only be carried out "holistically" by studying the individuals locally and immediately. Methodologically, the researcher must have participants reveal their constructions through the use of artifacts such as interviews, products, and writings. Because some methods emerge during a research study the research must be flexible and adaptive. The researcher uses descriptions of what is observed rather than the numerical data collected in quantitative studies. All the while the researcher is discovering patterns and themes through these observations. Quantitative analysis of data can compliment these discoveries by confirming them (Gall et al. 1996).

Educational research is a complex web of diverse approaches to understanding. The paradigm wars have liberated the investigator by encouraging creativity and different approaches to problem solving while at the same time requiring structured approaches that aim for internal validity. However, post positivism (constructivism)

does not mean anything goes. The research question is critical and dictates the research design that will best answer it (Tashakkori & Teddlie, 1998).

Numerous researchers (Atkinson, Heath & Chenail, 1991; Gall, Borg, & Gall, 1996; Patton, 1990; Spradley, 1980; and Tashakkori & Teddlie, 1998) have analyzed the strengths and weaknesses of both quantitative and qualitative design. Quantitative methods provide an empirical approach to a problem and solutions that generalize to a larger population. Qualitative research provides an in-depth study of a smaller sample. Quantitative research is standardized and aimed at being objective. Its deductive approach collects data to support or refute a theory or hypothesis. Qualitative, on the other hand, involves the researcher as “instrument” and is open to different interpretations by the participant, the observer, and the reader.

Learning is a complex human phenomenon and as such is both individualistic and context dependent. The naturalistic inquiry of qualitative research enables the researcher to enter the environment of the learner and attempt to understand the individual case and/or event as a whole. Change is evident as learners construct understandings through their interactions with the setting, other learners, and their teacher (Patton, 1990). Using naturalistic inquiry, the researcher examines the parts to understand the whole, which enfolds back onto its parts in a kind of hermeneutic circle. Gall et al. (1990), in stating a case for qualitative methods as used in the educational field, emphasized that the perspective of the participants is necessary to the understanding of an event.

The apparent dichotomy of the qualitative versus quantitative research approaches does not require that only one or the other be used. Both types of research

design may be used together in a mixed methods approach or in mixed model studies. They complement each other and were used together in this study to add to the body of knowledge about learning science.

This study focused on the use of three different instructional strategies to teach microbiology concepts to high school students. The teachers facilitated a standards-based learning environment that allowed students to explore and experience novel concepts empowered by their own independence and motivation. Prominent features of this environment were exposure to cutting edge biofilm research, access to relevant information, opportunities to communicate with real-world scientists, and time to be creative, problem-solve, support, and exchange ideas with teachers, peers, and middle school students and express visually, verbally, and in writing their newly acquired understandings. The teacher-researcher explored and scrutinized the events and the actors as these students succeeded or failed at meaning making. The emphasis was on how they learned, not how much they learned. When the study began it was thought that the stage was set for making great strides in learning and that the anticipated success would motivate the students in science.

### **Research Questions**

This study attempted to answer the question: How do biofilm-focused instructional strategies used with female high school biology students and middle school students affect a) the selected female high school students' understanding of selected microbiology concepts and b) their motivation to study science?

The sub-questions are

1. Does the cutting edge science of biofilm research and interactive communication with biofilm researchers help engage these female high school biology students in learning microbiology?
2. How do these high school biology students' instructional adaptations of an instructional video on biofilms for middle school students reflect their own progress in meaningful microbiological learning?
3. How do these cross-age teachers (female high school biology students) use an American Society for Microbiology (ASM) biofilm imagebase as an instructional tool to accomplish their goals?

### **Research Design**

A sequential mixed model study was used as a means of gaining a variety of perspectives and a richer understanding of the stated problem (Tashakkori & Teddlie, 1998). The objects and events that were observed and the records that were made and analyzed are shown in the Gowin's Vee diagram (see Appendix A). The sequence of events that took place are represented by a flow chart (see Appendix B). This was an exploratory study that had a quantitative component and a qualitative component in its research design.

The quantitative component consisted of student responses to pre- and posttests. Qualitative data collection began when participating teachers introduced the unit on ecology. Sequential data collection continued throughout the study and the triangulation of data sources and methods of analysis as shown in figure 1 insured validity and reliability.



## **Research Participants**

### **High School Biology Student Profiles**

Purposeful sampling was used in selecting biology classes in a girls' parochial high school in the Deep South identified by the pseudonym, Millville Academy. The research was an exploratory study across these students instead of being directed towards individual cases. This sample of convenience was chosen because the students have extensive experience with computer technology, have a great deal of administrative, teacher, and parental support to study science, have teachers who have been educated about the National Science Education Standards, and is the assigned school of this teacher-researcher. Minimizing confounding variables helped maintain the focus of the study on the goals of female high school student understanding and motivation. Other reasons for the selection are enumerated under the site description.

Students in two of the school's five biology classes participated in the study: three classes of the teacher-researcher (5<sup>th</sup>-, 6<sup>th</sup> -, and 8<sup>th</sup> -hour) and two classes of Teacher 2 (7<sup>th</sup>- and 8<sup>th</sup>-hour). The study began with three teachers but Teacher 1 dropped out early in the study. She cited her reason as not being able to consistently access the Internet during her first period biology class. Most of the students were 10<sup>th</sup>-graders, with some being 9<sup>th</sup>-graders and they ranged in age from 14 - 16. Biology at Millville Academy is usually preceded by physical or general science and is a requirement for chemistry, which follows it in the sequence of high school science courses. All participants except the 9<sup>th</sup>-graders had completed a physical science course. Most high school students in the state take biology for fulfillment of the minimum high school graduation requirement of two credits in science. Most students

in this school complete four years of high school science including the core courses- biology, chemistry and physics.

Available data (Table 1) shows the mean ACT™ composite score for Millville Academy in 1999 to be above the state and national means. The 1999 mean sophomore student PLAN composite was 21. This PLAN score predicts a mean ACT™ composite score of 22 - 26.

Table 1

Comparison of Standardized Test Scores (1999 – 2000)

| <u>Students</u>   | <u>Score</u>       |                      |
|-------------------|--------------------|----------------------|
|                   | <u>M composite</u> | <u>Estimated ACT</u> |
|                   | <u>ACT</u>         |                      |
| Millville Academy | 24.2               |                      |
| Deep South State  | 19.6               |                      |
| National          | 21.0               |                      |
|                   | <u>PLAN</u>        |                      |
| All biology       | 21.0               | 22 – 26              |
| CAT               | 20.0               | 20 – 24              |

The student participants totaled 104 students with a subgroup of 23 students who were Cross Age Teachers (CAT) and taught the middle school classes. The 1999 mean PLAN composite score for the CAT group minus two freshmen who did not have scores was 20 with a range of 17 - 24. A second subgroup of 12 CAT students, included six

students from each teacher participant's classes, who were interviewed by the teacher-researcher. This included two students each of high ability, average ability, and low ability as determined by individual PLAN composite scores and consultation with the chairman of Millville Academy's Guidance Department.

### **Middle School Student Profiles**

There were 250 middle school student participants in science classes from two middle schools that feed into the high school. There were 168 6<sup>th</sup>-graders from three classes each at Action Middle School and Granite Middle School and three 7<sup>th</sup>-grade classes with a total of 82 students also at Granite Middle School. Pseudonyms were used for the school names. Students in one 5<sup>th</sup>-grade class at the local university's laboratory school field tested A Biofilm's Bio, the instructional video used in the research. The 5<sup>th</sup>-grade teacher offered insights into the video such as the video being slightly fast paced. The high school teachers paused the video at selected points in order to reduce any effects due to the fast pace thus allowing students time to think about and discuss the information.

### **Teacher Participant Profiles**

The study began with three high school teacher participants, each having state teacher certification in biology. Teacher 2 and the teacher-researcher completed the study. Three parochial middle school teachers participated in the cross-age teaching portion of the study by reporting their observations and perceptions of the teaching (see Appendix C). The table shows the high level of combined experience that contributes to the validity of their observations.

The teacher-researcher developed the instructional activities and instructed Teacher 2 in how to use them (Appendix D). The teachers had a strong interest and content knowledge in microbiology and ecology. Both teachers regularly worked together and with other science teachers to develop a cohesive biology curriculum based on the school's philosophy and state and national science education standards. They reported that their preferred instructional methods included cooperative learning and inquiry activities that support a student-centered learning environment in which the teacher is a facilitator. Teacher 2 had 15 years teaching experience and a bachelor's degree and the teacher-researcher had 20 years experience and was a doctoral candidate. Teacher 2 reported having had about four hours of instruction in the national science education standards and the teacher-researcher had instructed other teachers in the standards. Both were at an advanced level of computer expertise. At the time of the study Teacher 2 taught biology and physical science and the teacher-researcher taught biology, advanced placement biology, and chemistry II.

### **The Research Site**

#### **History of Academic Excellence**

All identifiers that are used in this research are pseudonyms. Millville Academy, the research site, was purposefully chosen. Founded in 1868, it is a parochial, college preparatory school for girls, serving grades 9 – 12 and located in the capital city of a state in the Deep South. The city of 350,000, located in a metropolitan area of 500,000, is home to two universities. Approximately 40 of the 750 students enrolled are minority students and the student population represents a range of socioeconomic groups. Almost 97% of the graduates attend four-year colleges or

universities. The faculty consists of professional educators, two-thirds of whom have advanced degrees. Salaries approach the southern regional average. The Southern Association of Catholic Schools (SACS) and the State Department of Education accredit the school.

In 1991 and 1996 it was named a Blue Ribbon School of Excellence by the U.S. Department of Education. In 1998, there were 6 National Merit Scholarship Program Merit Semifinalists, seven Merit Commended students, and one Achievement Semifinalist. Three units of science and a total of 24 units of high school credit are required for graduation. Honors and Advanced Placement courses are offered and an honors diploma is offered upon successful completion of nine honors credit hours.

As previously mentioned, this school was selected for several reasons. This teacher-researcher has taught science at the school for the past seven years. This experience at the school enables the teacher-researcher to bring a keen sense of introspection and context knowledge to the study. Because the school is a relatively homogeneous population in several respects, several confounding variables may be reduced or eliminated.

Of interest to the teacher-researcher is how to increase motivation and performance of girls in science. Women are an underrepresented group in the science career ranks. Girls have been found to underachieve in science classes, to be generally unmotivated, and to have lower self-esteem in relation to their ability in science. Science education research indicates that females may have the most to gain from improved instructional strategies in science (Kahle, 1992).

## **Vision**

The school has a strong focus on science as evidenced by both the construction of a new science facility with state-of-the-art classrooms and equipment and by the independent research projects that all students are required to complete. The teacher-researcher originated the annual school science fair that the Biology Honors students are required to enter. Students have received recognition for their research at the local, regional, state, and international level. Many students participate in summer science programs and research opportunities, and many pursue science related careers. The school also offers "Science and More!" which is a summer program for middle school girls.

The school has been undergoing an academic audit for the past six years under the direction of a professional consultant in curriculum and instruction. Teachers have been designing new curricula based on the school's philosophy, and national and state curricular standards. Computer technology was integrated into the school over a six year period with training and proficiency testing for students and teachers. Since the fall of 2000 all entering freshmen were required to purchase a laptop computer. The computers are networked and wireless cards allow students to access the Internet from any location on campus. There is a full-time computer technician and three educational tech people, each of whom is assigned to assist teachers within specific departments. The school is the focus of a computer technology case study being conducted by a local university and is a participant in a National Science Foundation research grant to monitor computer-based learning in math and science. The teacher-researcher is on a four member school team selected to participate in a national supercomputing

leadership program. There is also a consultant from a major university supercomputing center who advises the administration and teachers on how best to integrate this technology into each discipline. Each science lab has a classroom computer, a large-screen color TV, video player, videodisc player, and computer video display connections. There are several projectors, LCD panels, video cameras, a digital camera, a video microscopy camera, and an Edcart available for classroom use on a regular basis. Teacher training in computer technology and support from the administration are evident, which facilitates the use of this technology as an instructional tool (Greenberg, et al, 1998).

Experience with computers insured that observations truly reflected the use of the images themselves. To facilitate the use of the biofilm imagebase, a pilot study was conducted to determine what computer instruction the teacher would need to provide students using the ASM CD-ROM biofilm imagebase. This study also revealed information about cooperative groups and how students within them use computers in science classes at the high school. Because these students and teachers have strong computer skills, the amount of training time involved and the expense of the proposed study was reduced.

There is some annual turnover in instructional staff at Millville Academy; however, efforts are made to provide continuity in the science curriculum. The school has participated in an ongoing academic audit under the direction of outside consultants who are curriculum specialists. Teachers play an ongoing role in planning the scope, sequence, and evaluation of the disciplines so that each graduate will have a comparable learning experience. This helped minimize differences in the high school students' prior

knowledge. Though individual teaching strategies vary, cooperative group learning is an integral part of instruction. Thus, the novelty effect of cooperative learning can be eliminated as a confounding variable.

The subjectivity of the teacher-researcher is of great importance in the qualitative portion of any study because the teacher-researcher is the instrument of measurement. The opinions, perspectives, knowledge, and values of the teacher-researcher influenced the interpretations that were made. The individuals being observed also interacted with the participant observer and their cognitive and motivation-related responses were often in the form of dialogue between the observer and the observed.

The quantitative component of this research project focused on measurable student outcomes. The qualitative component centered on the learning process (on how microbiology is learned). The experiences of students with students, and teacher with students offered insight into how learning occurred.

### **Data Collection Procedures**

#### **Spring, 1998 Pilot Study**

A pilot study (see Appendix E) was conducted in the spring of 1998 that consisted of a multi-case study of how female high school Biology I Honors students cognitively processed the ASM biofilm imagebase. The purpose of this phenomenological study was to develop an understanding of how selected female high school biology students used the ASM CD-ROM biofilm imagebase and how they accessed the images.



Data from the pilot study was to be used to develop user friendly instructions that would facilitate student access to the biofilm imagebase. It was thought that this larger study could then focus on innovative instructional strategies and their contributions to student understanding and motivation. The goal of the pilot study was to reduce both student frustration and the time needed to access and manipulate the images. With this accomplished, the images would serve as both a resource and a motivational tool that could stimulate student inquiry into the microbial world.

The pilot study followed the guidelines recommended by Spradley (1980) and began with a general descriptive observation, or grand tour. The general research question was, what is happening as female high school biology students process the database of biofilm images? Some of the questions that guided my mini-tour observations were

- 1) How can I describe all the actors and their acts, activities, events, and goals?
- 2) What are all the feelings the students harbor and express during the observations?
- 3) What is it like to work in a group or to work alone?

An important finding in the pilot study was that the CD-ROM imagebase had inherent technical flaws that impeded the student's use. In addition, the level of student computer expertise at that time was not uniform and software that was needed for the student image projects was not available to them. Fortunately, the imagebase was put online as the third edition of The Microbial World in 1997. This made the images more accessible to the students.

There is even more coherence between the pilot study and this research. The pilot study also led indirectly to the inclusion of biofilms in the Enviro-Tacklebox™ Module 1, which will eventually be shown all over the world. The production of the biofilm instructional video led to the idea of high school student's cross-age teaching middle school students.

### **American Society for Microbiology's (ASM) Biofilm Imagebase**

A description of the biofilm imagebase that participating students accessed is necessary to understanding how they also used the images as an instructional tool. Scientists are able to make observations about biofilms in numerous ways. One way is to study biofilms as a whole, or the macro level, where they are visible to the naked eye. Individual microorganisms are usually invisible and are studied at the micro level. Scientists employ various technologies to make biofilms and/or their microorganisms visible as images. This enables them to better study biofilms and the complex interactions of their microorganisms. Some of the technologies include macro photography, phase contrast microscopy, transmission electron microscopy (TEM), scanning electron microscopy (SEM), fluorescence microscopy, laser confocal microscopy, computerized diagrams, and computer models.

High school biology laboratories are not equipped to generate their own biofilm images. Addressing the need to facilitate the study of biofilms in pre-college and undergraduate classrooms, the educational section of the American Society for Microbiology (ASM) developed The Biofilm Project (ASM, 1996). The project began in 1995 in partnership with the Center for Biofilm Engineering and was funded by a grant from the Foundation for Microbiology. The Foundation was established in 1951

by a Nobel Laureate microbiologist, Selman A. Waksman, to promote innovative concepts in microbiology.

Five hundred copies of a CD-ROM, "Diversity in the Microbial World," were distributed to educators at the 1996 National Association of Biology Teachers national convention. The instructional material on the CD-ROM was donated by the scientific community and included text material, photographic images, electron micrographs, and archival images. Instructions for viewing, displaying, printing, and placing the images into computer-based presentation or graphics programs are stored on the CD-ROM (ASM, 1996). Because the images are in a database and not in a prepackaged software program, teachers and students have the flexibility needed to manipulate the images and construct meanings through active participation.

In 1998, a second edition of the CD-ROM was distributed by mail to educators who requested it. All copies of both editions of the CD-ROM were distributed and the supply was exhausted. More recently ASM has made the images, along with teacher resources, access to science mentors, and four lesson plans developed by educators, available to teachers and students online (ASM, 1999). Internet access to the images eliminated the technical problems inherent in the CD-ROM and was more convenient to use. For these reasons the ASM web page was used in the current research instead of the CD-ROM.

It was hoped, through communication with ASM members who helped design the imagebase, to develop an in-depth understanding of how images were selected for the project and how the scientific community attempts to interest students in microbiology and facilitate their understanding. It was also hoped that the experiences

of other teachers and/or students and how they adapted the images when learning microbiology concepts would aid this study. Unfortunately, ASM had not evaluated teacher use or the impact of the biofilm imagebase on student learning. ASM stated its goal is to serve as the premier source of information resources on microbes and increase microbial literacy among the public. To accomplish this goal they strive to offer peer-reviewed quality resources in a consistent format. It would be difficult to determine whether that goal was reached without user feedback on the CD-ROM. The biofilm image project was Phase I of ASM's outreach efforts; however, funding did not provide for follow up. ASM therefore had not evaluated the project and had no data on teacher use. Four model lessons using the biofilm imagebase, only one of which was at the high school level, were placed on the ASM web page but have not been updated to reflect changes in computer technology. The focus of the biofilm image project changed with the development of Phase II's digital microbial library. The library offers different types of resources, including images and curriculum ideas. Phase III of the project is the ongoing maintenance of the web page.

Teacher participants in this research also used other sources of information on microorganisms designed for K - 12 students. Teachers and the female high school biology students had access to these resources and used them to varying degrees. These included the video series Intimate Strangers: Unseen Life on Earth described on the Microbe World web page and shown on public television (ASM, 1999). Internet resources were the "Microbe World" (ASM, 1999), Maryland Sea Grant Education (1999), and the Center for Biofilm Engineering's web page (1999).

### **Enviro-Tacklebox™'s Instructional Video: A Biofilm's Bio**

The instructional video, A Biofilm's Bio is a component of Module 1 of the Enviro-Tacklebox™ project of the local public broadcasting television station in partnership with the Satellite Educational Resources Consortium (SERC) and is partially funded by a U. S. Department of Education Star School's grant (Ales, et al., 1999). The public television station granted permission to use the video in this study (Appendix N). Insight into how these biofilm-focused instructional strategies were developed contributed to understanding how students used them in learning microbiology.

The project's three major components include a series of Teleconferences that provide professional development for environmental science educators, Modules, or curriculum units, and Workshops for formal and informal educators. The standards-based Modules are composed of telelessons, a teacher guide and an interactive web page. These telelessons focus on environmental topics that fill the gap in environmental education resources for educators and provide a 20-minute video, background information for the teacher, and two classroom activities.

The teacher-researcher was a member of the Dream Team comprised of seven experts in science education whose responsibilities included the development of the modules and determining the science content of all components of the project. The development of the biofilm component of the Module 1 by the teacher-researcher is relevant to this research. The teacher-researcher focused on the concept of biofilms and researched the topic extensively, interviewed biofilm researchers, and developed inquiry-based biofilm activities after consultation with microbiology researchers and the

teacher-researcher's major advisor The Dream Team accepted the project because it represented cutting edge science not discussed in most text-books, was considered relevant to middle school students, and because biofilms have significant consequences in the environment. Figure 3 illustrates the stages in the completion of the Module. Primary factors that directed the development of A Biofilm's Bio were accurate science content and the real world development of technology and its implications for society.

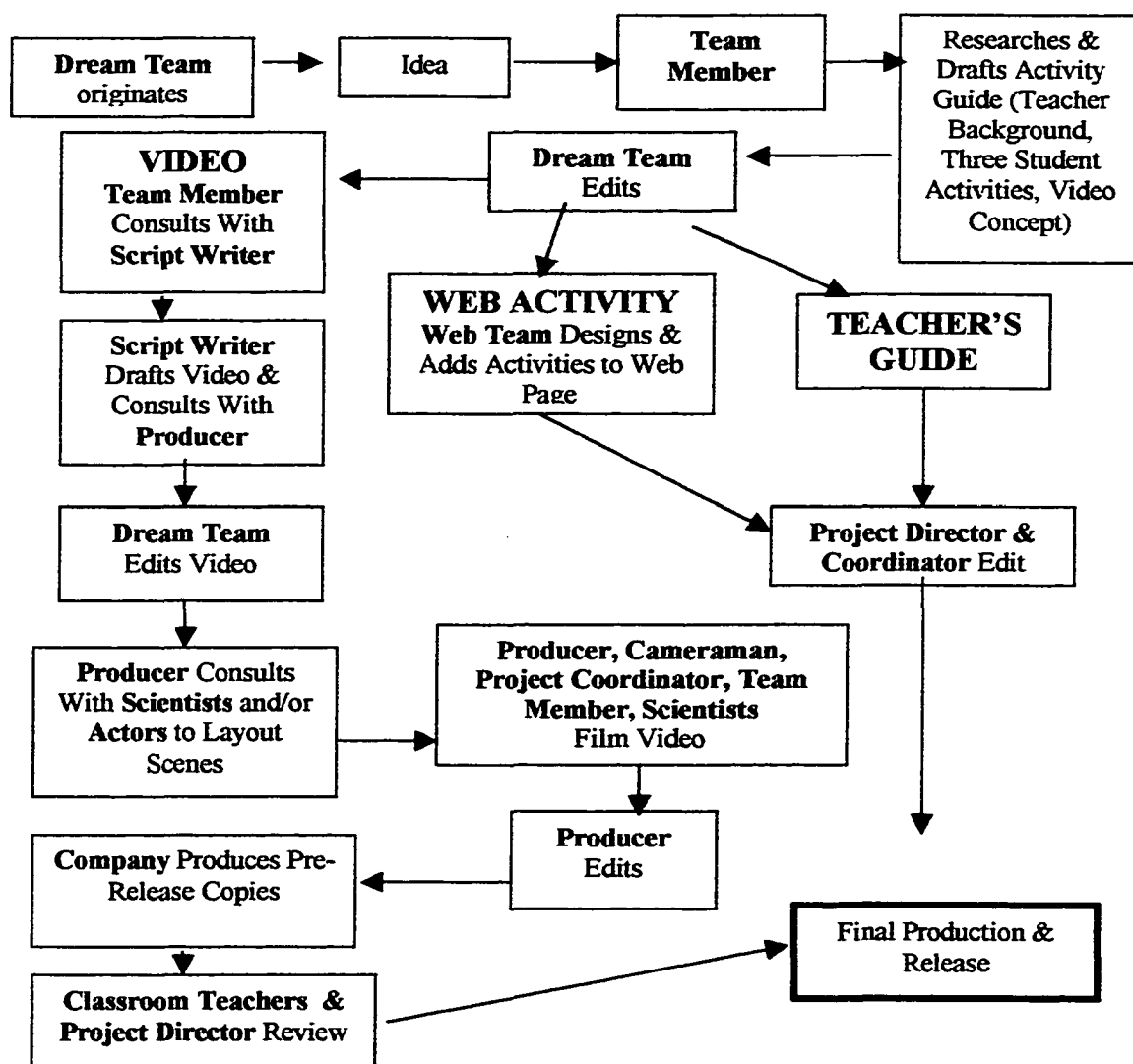


Figure 3. Flow diagram of the making of Enviro-Tacklebox™ Module 1, A Biofilm's Bio.

### **Producing the Video**

A goal of the video was that it be entertaining and capture and hold the interest of middle school students; however, content was stressed over showmanship. Ideas that were incorporated into the video include (a) biofilms as cutting edge science, (b) the relevance of biofilms to individuals and society, (c) the use of technology to control biofilms, (d) the use of biofilms in technology, and (e) unforeseen consequences of future technology. Educational theory and classroom pedagogy required that the video facilitate the connection of the science domain to the students' domain; taking the student via distance learning where she or he could not ordinarily go. Student viewers would experience objects and events through student actors, scientists, and Greg (the main voice) and construct understandings by connecting them to their prior knowledge. The teacher-researcher's ongoing communication with the scriptwriter, a well-known television reporter, ASM; and the Center for Biofilm Engineering assured accuracy of content. Another factor that was considered was the use of a limited number of key concepts and terms to insure depth of understanding over breadth. Terms that were introduced in the video and new to the student had to be defined.

Presentation style was considered a priority to insure that students would be engaged learners. Words, graphics, music, sound effects, and student and adult actors were carefully chosen and were culturally and developmentally appropriate in order to appeal to the audience. The video can also be adapted for high school students, which insures a wider audience range.

The video was filmed on location at a dentist's office, environmental research facilities at Louisiana State University, the Center for Biofilm Engineering at Montana

State University, and Yellowstone National Park. A common theme was used to link together all of the videos and their different topics. Greg (the narrator) always opens at a bait shop on a local swamp. He poses different environmental questions that are examined throughout the video. A group of middle to high school age teenagers interacts with Greg as he travels to different locations and develops understandings about the questions.

### **On Location**

The Enviro-Tacklebox™ project coordinator, producer, camera man, and the teacher-researcher traveled to Bozeman Montana where the Center for Biofilm Engineering is located in order to film the major portion of the video. The first afternoon of the video filming at the Center was spent touring the facilities and meeting with the Center's Operations Manager and two research scientists. These communications helped develop a consensus of how the final product could meet the goals of the project. For example, the producer and cameraman gained an understanding of the types of biofilms, how images of them are made and how they are studied. This enabled them to position lighting and camera angles to capture biofilms as they really exist in the environment. The group made changes to the script and ideas were discussed including (a) which images would show up best on film, (b) which biofilm samples would the students be more familiar with, (c) what are the requirements of biofilms for growth and attachment, (d) where to film in Yellowstone National Park, and (e) which scientists would have roles in the video.

Bill and Mary (pseudonyms), the two scientists, continually emphasized that the old ideas of what bacteria are have changed. Science has revealed that the ecology of



bacteria is more important today. This is extremely different from classical microbiology and the way students are taught about bacteria should change to reflect that. They also stressed that studying biofilms is interdisciplinary and the Center joins together the efforts of engineers and biologists that often approach problems in different ways.

These discussions also revealed that it was important for the producer who controlled the filming to understand biofilms and what is most important to know about them. The scientists also had to understand that the information had to be appropriate for middle and high school students. One issue for the producer was that white is the worst color to wear on camera. Lab safety is a priority in research labs and science classrooms and it had to be a priority in the video. During the filming when the scientists were working in the lab they had to wear white lab coats and protective eyewear. The process of filming was arduous and time consuming and scenes were filmed numerous times over a two-day period until the team agreed that they were successfully done. At times conflicts arose between ideas of the team members but the teacher-researcher's and the project coordinator's presence was invaluable and insured that accurate science content and pedagogy were not sacrificed.

The video is fast-paced with high school age student actors learning about biofilms. Greg, the main character begins the video looking into the refrigerator at a bait shop on a local bayou and wonders just what is growing on the cottage cheese he finds there. His exclamations about the smell and "grossness" of the mysterious substance capture a middle school student's interest. Graphics, animation, and music help to keep the action moving and hold the attention of the viewer. Concepts that are

new to the student are superimposed on the frames to provide visual representations that enhance learning. The scope and sequence of the video is summarized in Figure 3.

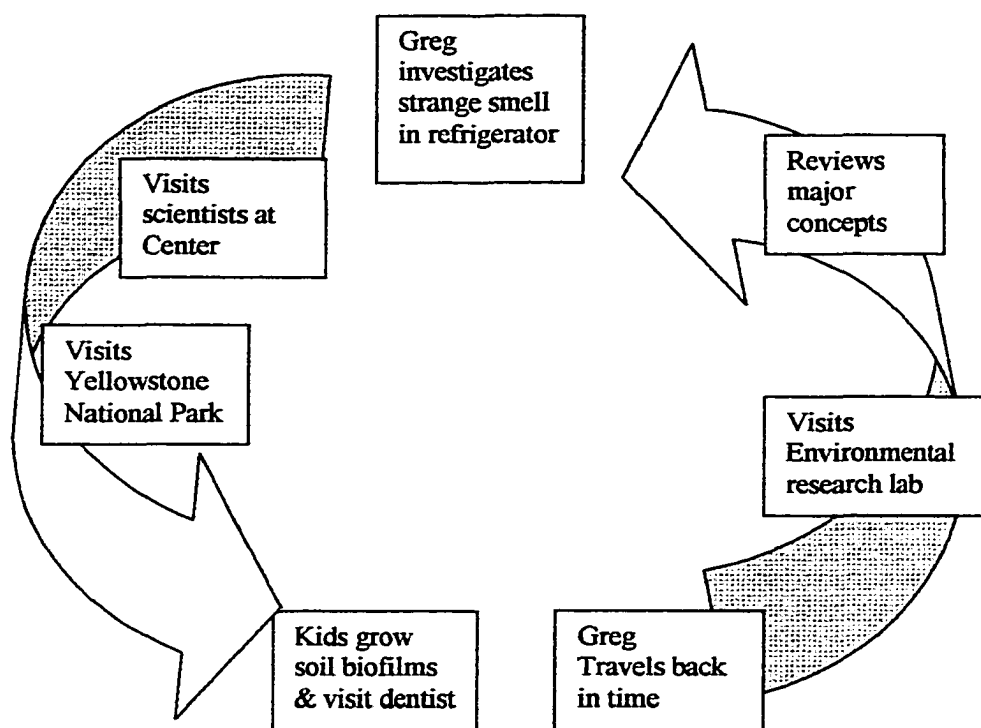


Figure 4. Scope and sequence of instructional video, A Biofilm's Bio.

Some science concepts that are developed in context in the video include biofilm, polysaccharide, biocorrosion, bioremediation, community, ecosystem, enzyme, microbial diversity, dental plaque, bioprospecting, and decomposer. Science as process is a theme throughout the video that reveals how scientists study biofilms, use biofilms in technology, and develop technology to control biofilms.

#### **Communication With Biofilm Research Scientists**

An important component of the research is the female high school biology students' computer assisted communication with biofilm research scientists through E-mail. The selected female, high school biology students communicated with biofilm

researchers while working in cooperative groups to construct the biofilm image products. In addition to communicating with the Operations Director for the Center the teacher-researcher laid the groundwork for this interaction by investigating the ASM online mentor information.

ASM provided online mentors through its Science Education Network (SEN) program. The program began as a way to help students and classroom teachers with specific requests that were not being met such as career information. SEN also matches classroom teachers with scientists in hopes of forming mentoring relationships. In May 2000, there were 116 scientists listed in the database. The scientists do such things as answering questions, visiting classrooms, and donating used laboratory equipment. The program was re-designed in May 2000. Prior to this, ASM staff maintained a database of interested scientists. Students and teachers would call the staff directly or complete a request form online. Staff members then searched the database by state and gave the requestor the scientist's E-mail address and/or phone number. There has been no formal evaluation of the effectiveness of the program but students occasionally call ASM to report that they have received help from a scientist. Now students and/or teachers conduct the search themselves and E-mail the scientist(s). ASM will be able to see how many people have visited the web page and at the end of the first year will contact the scientists to ascertain more information such as the number of requests.

That ASM is interested in facilitating learning about microbiology in grades K-12 is evident in the establishment of SEN and other programs and its use of the National Science Education Standards in developing learning activities. However, when this teacher-researcher attempted to join the program and be matched with a scientist mentor

under the category of general microbiology or applied and environmental microbiology, there was not a scientist from this state in the database; thus a match could not be made.

The Center for Biofilm Engineering has E-mail addresses for all of its researchers on its web site indicating that they are accessible. Prior to instructing the high school biology students the researcher-mentor communicated with the Center the need for the high school students to be able to communicate with researchers. The Center was cooperative and offered its support in educating the public about biofilms.

Communicating with scientists has value in biology education research because the conventional wisdom is that connecting with scientists will enhance learning. Communicating with scientists may make science more relevant to students and enable them to make novel connections between knowledge. High school biology textbooks do not yet have information about biofilms and students must consult primary sources such as the biofilm researchers and biofilm-related World Wide Web sites, as well as science journals, and books; thus, becoming more responsible for their own learning while developing cognitive skills to filter and organize the information.

### **Gaining Entry to the Site**

Verbal permission was obtained from the local public broadcasting television station to use pre-release copies of the video and information in the Enviro-Tacklebox™ Module 1 during a unit on ecology (Ales, et al. 1999). A cooperative verbal agreement to conduct the study was obtained from the administrators of the high school and the participating biology teachers. Participating biology teachers were provided background information on biofilms found in the Enviro-Tacklebox™ Module 1, A Biofilm's Bio, a copy of the instructional video, and instructions and

guidelines to follow when teaching the ecology unit (see Appendix D). Entry to the middle schools was afforded by each principal (Appendix F). The research was begun after approval by the university's Institutional Review Board (IRB) (Appendix G) and parental consent and student assent were obtained (see Appendix H & I) for the middle school students and cross age teachers (CAT). Parental consent and student assent for the high school biology students who did not teach middle school students (NCAT) students was obtained through procedures used by the high school. All identifiers used in this research are pseudonyms.

### **Learning Activities**

#### **Introduction to Students**

The female high school biology students participated in the research study during the fall and spring of the 1999 - 2000 school year. Raw data from observations recorded in teacher-researcher field notes, video tapes, and documents were collected continuously during the study. First students were tested on their prior knowledge about general microbiology and ecology concepts and biofilms using the pre-test (Appendix J). Qualitative data collection began when participating teachers in identical rooms connected by a lab preparatory room used the background information in A Biofilm's Bio Activity Guide and the accompanying 20-minute instructional video to introduce the ecology unit to the selected female high school students. Teachers roughly followed the sequence shown in Appendix D and used the pause function on the video player to stop the videotape for class discussion and elaboration of concepts. Students were instructed to take notes while viewing.

Slavin's criteria for structuring mixed-ability, effective small groups was used to set up the cooperative groups (Doran, Chan, & Tamir, 1999) after viewing the video. Cooperative groups of four students within each biology class were assigned to assure diversity and increase internal validity. Cooperative group interaction in the teacher-researcher's 5<sup>th</sup>-hour class and Teacher 2's 8<sup>th</sup>-hour was videotaped daily. Group members chose their individual group roles that included recorder, facilitator, mentor contact, and supply manager. While the facilitator led the group, the recorder was responsible for keeping a daily record of group actions in her binder entitled Biofilm Project. The mentor contact was to locate and communicate with biofilm researchers and keep records of all E-mail messages sent and received. The supply manager made sure that the agreed upon supplies such as poster paper were brought to school when needed. There was little evidence of role swapping throughout the duration of the project.

The teachers presented a general introduction to the unit and the biofilm image project. Directions were first given on the second day of the project and reinforced periodically. These directions were initially flexible but became more structured as the students and teachers co-developed the criteria and rubrics. Students were encouraged to participate in the goal setting and decision-making that occurred throughout the duration of the project.

Each group began to grow its own soil biofilm as shown in the video by wrapping a plastic knife in a piece of paper toweling and then placing it in the ground just outside the classroom. These were examined macroscopically and microscopically

for biofilm growth approximately three weeks later. Students could begin to develop understandings about how and where biofilms grow through this experience.

### **Students Progress Through the Unit**

After the two days of introductory activities, the students freely explored the ASM web site and imagebase. The teacher-facilitated stages of the project were biofilm selection and research, biofilm image selection and product design, construction of the product, and peer presentation. All students took part in these phases. Each group selected a specific biofilm for its project and began to gather information and images and contact biofilm researchers as mentors. Emphasis was placed on using the image to help others understand about biofilms and ecology. The teachers informed the students that both science content and the use of the image would be evaluated as to their contributions to understanding. They were instructed to plan a peer presentation that their peers would understand and learn from. Students spent from eight to nine class days constructing the biofilm image projects and preparing their presentations. Group presentations of no longer than 10 minutes each were made over a two-day period. Their peers were instructed to record information about each biofilm presentation. Questions related to ecology, including biofilms, were included on the mid-term exam that was given about one month after the presentations and also on the final exam at the end of the year. These test results were not included in this study because they consisted of only a few questions on the exam and the time that elapsed between learning and testing was considered to be too short to effectively measure delayed retention. However it provided evidence that most students learned the basic concepts. During the last five minutes of each class period each student recorded her reflections

on the biofilm project in her journal section of the binder. Reflection leads to new ways of thinking and novel ideas (Norman, 1993) and is integral to this study.

The recorder also made daily records of the group's accomplishments. The mentor contact sent and received E-mail communications with biofilm researchers and kept the actual documents in her binder. In addition to the posttest, all students completed a debriefing questionnaire about the project (Appendix X). A content analysis of student perceptions of the three instructional strategies as observed and/or recorded in the documents was then made by the teacher-researcher.

### **Biofilm Image Products and Peer Presentations**

Appendix K lists the types of biofilm image products that the groups constructed. Eleven of the 19 products focused on medical/dental biofilms, eight on environmental biofilms, and none on industrial biofilms. Appendix L shows the student-teacher developed rubric used to assess the biofilm image product and presentation. Students were informed that they needed to include the content criteria listed in the checklist in their presentations. In addition, students were assessed on their use of the biofilm images, oral communication skills, and their attempts to communicate with researchers. Cooperative group interactions were also assessed using both peer and self-evaluation completed by each student (Appendix M). This enabled the teachers to avoid assigning a single grade for the group effort and helped identify "loafers" who were "trying to get a free ride". Students knew that they were expected to participate fully and learn from the experiences. Selected peer presentations were videotaped; one in Teacher 2's and five in the teacher-researcher's classes. Each presentation and image product was evaluated using the student-teacher co-constructed



rubric. The teacher-researcher also evaluated one of Teacher 2's group presentations in her absence. A student was assigned to take 35mm photographs of each group and its product to help document the presentations. The biofilm products were also kept for more extensive analysis later. Field notes were recorded by the teacher-researcher and discussions with Teacher 2 were ongoing.

### **Cross-Age Teaching**

In the final phase of the study, a sub group of 23 female high school biology teacher volunteers (CAT) adapted the instructional video, A Biofilm's Bio and their student-developed biofilm image product to cross-age teach middle school students microbiology concepts. Permission to use the video was granted by the project sponsor (Appendix N). The teaching took place over two consecutive days about three months after the peer presentations. Biology students were on a holiday and the middle school students were not. This enabled the students to teach without missing their own classes. The original design was for trained student observers to go with the cross-age teachers to videotape and to record observations about the teaching experience because the teacher-researcher could not leave her teaching assignment. However, the teacher-researcher was able to go with the cross-age teachers and assist them and make observations.

The teacher-researcher, influenced by human constructivism, met with the CAT students a few days before teaching and related knowledge about how students learn (Appendix O) after which they used the instructional video and their imagebase products to cross-age teach middle school students. Middle school teachers obtained parental consent for their students and gave them the pre-test on biofilms. Following

the presentations the students were also given the posttest. These were not analyzed because middle school student outcomes were not a focus of this study.

Each CAT group consisting of two or three students taught a single class of 6<sup>th</sup>- or 7<sup>th</sup>- graders with a total of nine presentations. Another student videotaped the presentations. Each group was instructed to show A Biofilm's Bio to introduce the topic of biofilms and provide general conceptual information. CATs used the pause function to stop the video and engage the middle school students in discussion through questioning and answering. In each class the students remained attentive and appeared to be interested throughout the presentation. Both the 6<sup>th</sup> and 7<sup>th</sup> graders answered questions readily though the 7<sup>th</sup> graders were more assertive. Finally the group presented its biofilm image product and explained its specific biofilm. Following another round of questions and answers, the presentation ended.

### **Clinical Interviews**

Clinical interviews were carried out two months following the cross-age teaching in order to gain insight into long-term memories and delayed retention rates. Each interviewee was chosen on the basis of her communication skills and science performance in biology class and on standardized tests after consultation with the guidance department. Interviewees included two high level, two medium level, and two low level achieving students from each teacher. Each student was interviewed for her reactions to the instructional strategies and her awareness and understanding of the learning process. The videotaped structured interviews were approximately 15 minutes long and utilized co-constructed concept maps using the method of Wandersee and Abrams (1993). The videotapes and concept maps were analyzed for content.

A focus group discussion between seven of the CAT interviewees was also videotaped. These students were asked structured questions about the instructional strategies used in this study and how they impacted the cross-age teachers' microbiology understandings. They were also asked to rank the relative importance of each sub question to the two goals of the research: student understanding and motivation.

Because of time constraints structured interview questions were mailed to participating middle school teachers and analyzed when they were returned. These teachers, along with the teacher-researcher, were present during the cross-age teaching. The teacher-researcher's content analysis of all records revealed conceptual patterns in the qualitative data that estimate the relative contributions of the three instructional methods to student understanding of selected microbiology concepts and motivation in science.

These inquiry based cooperative activities that the students participated in were dynamic because students set goals, planned and designed approaches to problems, investigated alternatives, changed their direction, and negotiated meanings with the other members of their groups. Throughout the inquiry-based unit, the students charted their own way (using human and instructional resources) towards modeling a biofilm. Students were free to apply their constructed knowledge of biofilms to experiences in their own lives.

### **Protection of Human Subjects**

After this proposal was edited and approved by the doctoral committee, it was submitted to the University's Institutional Review Board (IRB) representative in the College of Education for approval, as exempt from full IRB review. As previously

mentioned entry into the site was obtained through the verbal approval of the school's administrator. A letter explaining the research study was sent to the participating high school cross age teachers and middle school students and parents for their agreement (see Appendices H & I). Parents of the NCAT female high school biology students indicated their consent by signing an agreement after reading the Millville School Student Handbook (Appendix P). Anonymity was maintained at all times through the use of pseudonyms. Upon completion of the study, the principal, participants, and parents were informed of the results. As part of the agreement with the local public broadcasting television station they were also informed of the results of the study.

### **Summary**

The methods that were chosen for the study were grounded in prior research that supports the application of both qualitative and quantitative data collection and analysis. The teacher and student participants and the school setting represent best conditions for learning. The curriculum model was developed by the teacher-researcher who also contributed to the design and production of the instructional video. Each strategy was purposely chosen to correspond with the National Science Education Standards (NRC, 1996).

## **RESULTS AND DISCUSSION**

This study was driven by the research question and sub questions which asked how biofilm-focused instructional strategies used with selected female, high school biology students contributed to their understanding of selected microbiology concepts and principles and their motivation to study science. The results are ordered in relation to the research question and the three sub-questions that the study addressed. A rich description of what the students did and how they did it informed the teacher-researcher and lead to interpretations upon which the conclusions are based.

### **Quantitative Data**

#### **Written Test as Measuring Instrument**

The quantitative component of this research focused on measurable student outcomes. Statistical analysis of the pre- and posttest data assessed the effects of cross age teaching on the high school students' learning and retention of selected microbiology concepts (see Appendix Q). Content validity of the teacher-researcher constructed pre- and posttest was determined by professional peer review of the instruments by members of the doctoral committee and Teacher 2. This was aimed at providing test scores from which valid inferences could be made. The concepts and principles that were tested correlate with the national science education standards (see Appendix R). They also correlate with the content background provided the teachers, information from the ASM web page, and the instructional video. Consultation with a statistician in the design and execution of the study contributed to the instrument's reliability. The test consisted of 10 multiple-choice and 12 open-ended response items that applied concepts of scientific literacy including: "a) mastery of science content, b)

understanding the relationship between science and society, c) understanding science as process, and d) knowledge of the socio-historical development of science." (Mitman, Mergendoller, Marchman & Packer, 1987) These represent multidimensional-level scientific or biological literacy.

Approximately 57% of the high school biology students self reported that they had previous experience learning microbiology in middle school. Correct responses to the multiple-choice questions indicated the ability to recall memorized, isolated facts, known as rote learning, of microbiology concepts. Scores on the pre-test multiple-choice questions measured prior knowledge. The comparison of these scores with posttest scores indicated whether CAT students retained more information than NCAT students after a four-month delay. Only scores from student participants who took both the pre- and posttests were included.

Mean scores represent the average number of correct responses on the test out of a possible nine questions. An additional question that asked students to identify the father of modern microbiology was included on the test as a check to determine whether teaching was from a traditional microbiology perspective. Because no one correctly identified Louis Pasteur on the posttest this indicated that the teachers were teaching microbiology in the innovative context of cutting edge science rather than emphasizing classical microbiology. This question was not part of the statistical analysis. Neither could CAT teachers recall the father of modern microbiology when asked to do so by the middle school students.

### **Statistical Analysis of Multiple-Choice Questions**

Results on the multiple-choice section indicate no significant difference at an  $\alpha$  level of 0.05 in the mean scores between the Non Cross-Age Teachers (NCAT) and the Cross-Age Teachers (CAT) pre-test and posttest scores either within or between groups. Mean scores, differences in CAT - NCAT, standard error, t-values, Wilcoxon signed rank test, and probabilities are shown in Table 2. The two-tailed paired t-test showed that the NCAT group scored slightly higher than the CAT group on both the pre- and posttests, though not significantly. The effect size between NCAT and CAT learning outcomes was determined to be -0.22 and is not of practical significance. Examination of the data recorded in the table shows that the NCAT group scored slightly higher on both the pre- and posttests as evidenced by the respective means and the pre-test scores were almost significantly different (0.07). The Wilcoxon signed rank test showed the NCAT group did score significantly higher on the pre-test and posttest than the CAT group when one-tailed. This indicates that the NCAT students may have begun the project with a higher ability to recall information about microbiology. The NCAT group also showed a significant improvement in score over the CAT group. Tests were scored by the teacher-researcher with consultation with Teacher 2.

To increase reliability, both teacher participants administered the tests under controlled conditions in the classrooms where the students were normally tested. Students did not receive a grade on either test but were assigned measured scores on their biofilm image products and peer presentations. The concept maps that the 12 CAT students generated during clinical interviews were also graded.

Table 2

**Comparison of Student Multiple-Choice Scores**

| Variable | N  | Mean | Difference<br>(CAT– NCAT) | Std Err | t-<br>value | Two-<br>tailed<br>p-value | Wilcoxon<br>one-<br>tailed<br>p-value |
|----------|----|------|---------------------------|---------|-------------|---------------------------|---------------------------------------|
| Pre-test |    |      | -0.66                     | 0.36    | -1.84       | 0.07                      | 0.03                                  |
| NCAT     | 70 | 4.89 |                           |         |             |                           |                                       |
| CAT      | 18 | 4.22 |                           |         |             |                           |                                       |
| Posttest |    |      | -0.62                     | 0.40    | -1.54       | 0.13                      | 0.03                                  |
| NCAT     | 70 | 5.96 |                           |         |             |                           |                                       |
| CAT      | 18 | 5.33 |                           |         |             |                           |                                       |
| Post–Pre |    |      | -0.04                     | 0.47    | -0.09       | 0.13                      | 0.38                                  |
|          | 70 | 1.07 |                           |         |             |                           |                                       |
|          | 18 | 1.11 |                           |         |             |                           |                                       |

**Statistical Analysis of Open-Ended Responses**

Results from the pre- and posttest open-ended responses indicate no significant difference in the mean percent scores both within and between the NCAT and CAT groups. Mean percent, standard error, t-value, and probabilities for the pre- and posttests for both CAT and NCAT groups are shown in Table 3. The percentage score was computed as the average percent correct on each question, averaged over the 11 questions. The CAT students scored almost significantly better on the posttest at  $\alpha=0.05$ . Tests for homogeneous variances showed no significant difference. Question



11 of the 12 open-ended questions was not included in the statistical analysis because it asked students to self-report whether they had prior experience learning microbiology.

It is important to note the amount of improvement in score from pre-test to posttest for each question. As an example, 83.33% of the CAT students could give an explanation of what a biofilm is on the posttest whereas 0% could on the pre-test. Of these explanations, 27.78% were judged to show quality understanding of biofilms. In contrast, 15.71% of NCAT students were unable to explain biofilms. Approximately 84% of the NCAT students could adequately explain what biofilms are.

Table 3

Comparison of Student Scores on Open-Ended Questions

| Variable   | N  | Mean  | Std Err | t-value | Two-tailed p-value | Wilcoxon one-tailed p-value |
|------------|----|-------|---------|---------|--------------------|-----------------------------|
| Pre-test   |    |       |         | -0.24   | 0.81               | 0.42                        |
| NCAT       | 70 | 26.68 | 1.13    |         |                    |                             |
| CAT        | 18 | 27.27 | 2.25    |         |                    |                             |
| Posttest   |    |       |         | -1.89   | 0.07*              | 0.08                        |
| NCAT       | 70 | 42.51 | 1.10    |         |                    |                             |
| CAT        | 18 | 46.13 | 1.57    |         |                    |                             |
| Post - Pre |    |       |         | -1.05   | 0.30               | 0.24                        |
| NCAT       | 70 | 15.83 | 1.36    |         |                    |                             |
| CAT        | 18 | 18.86 | 2.54    |         |                    |                             |

### **Factors Affecting Test Results**

Though no significant increase in microbiology knowledge was indicated on either the multiple-choice or open-ended sections both CAT and NCAT groups improved. These findings suggest that learning occurred when the three instructional strategies were used. However, the test may not have been able to detect any differences in understanding resulting from cross age teaching that are however, indicated under the qualitative data analysis. A factor that may have affected the test results is the small sample size (18) of the CAT group. This made it hard to detect a significant difference. In addition, the amount of time that elapsed between teaching the unit and testing (four months) may have been too long. Though teaching occurred over 9 or 10 days, on the day of the posttest a few students reacted negatively and asked why the class was still studying biofilms. The students seemed to misunderstand the purpose of the posttest and their attitudes may have affected how they responded to the test questions.

It has been proposed that methods that are used to evaluate learning today need to be multifaceted in order to offer valid assessments (Doran, et al. 1999). These findings support the National Science Education Standards (1996) recommendation that authentic assessments be used to evaluate student understandings and acquired skills. The pre-test and posttest provided insights into the types of knowledge gains made by the students

The biofilm image project, student reflections, student explanations given during peer and cross-age teaching, generation of concept maps, and self-reported changes discussed later in this section contrasted with the written test and indicated that

the three instructional strategies were effective. Individual differences in student performance, which were expected, were also found. Though guided and supported by the teachers the students were able to work independently and gained basic understandings from the video, images, and to some degree communication with biofilm researchers. There was evidence of an increase in the ability to transform this basic knowledge into more abstract concepts as they adapted the images and the video.

Supporting this argument is evidence that although no significant differences were found student understanding did improve. A closer examination of question 1 on the pre-test showed that only two students (2.27%) could correctly complete the phrase, "A biofilm is...". There was an improvement on the posttest because 75 students (85.23%) had some idea after being exposed to the three teaching strategies. Of these, 29 students (33%) were able to give higher quality explanations of biofilms. Generally they described them as being communities of microorganisms that attach to surfaces in moist, nutrient-rich environments that sometimes contain oxygen and was considered to be a quality explanation.

How the question was asked may have been interpreted by the students as a fill-in-the-blank type question that required their immediate recall. Though a correct response may indicate that the student has knowledge of a concept it did not distinguish the higher goal of understanding. The students generally wrote brief responses in their journals and may have needed prompting to elaborate their understandings of biofilms. Even during the clinical interviews many of the students seemed to hold back their responses until prompted by the teacher-researcher. This indicates that when students

spend more time thinking and reflecting on their understandings they reveal deeper understandings and more meaningful learning.

It is interesting to note that even though the students were introduced to new technologies that use biofilms to help mankind such as sewage treatment and bioremediation most did not mention these on the posttest. They could quickly identify them as being helpful and harmful but did not elaborate on the helpful actions of biofilms. When asked to report the first thing that came to mind when they thought of biofilms most gave a negative response. This indicates that the students' overall perceptions of bacteria did not change as a result of the teaching strategies.

These test results indicate that the instructional strategies used with the female high school biology students under best conditions did not improve the students' ability to retain either rote or meaningful learning after a four-month delay as measured by a written pre-test and posttest (Appendix J). The three teaching strategies contributed to patterns in the students' understandings as indicated by the qualitative observations and content analysis reported later in this section.

### **Changes in Motivation to Study Science**

All of the participating biology students were asked on the pre-test and posttest, How interested are you in finding out more about bacteria and biofilms? There was no change in percentage of NCAT and CAT students who were not very interested from the pre-test to the posttest. There was an increase among NCAT students from 4.28% very interested on the pre-test to 18.57% on the posttest. CAT students exhibited a decrease in interest among those who were very interested from 38.89% on the pre-test to 22.22% on the posttest. Many students wrote that they liked the project when they

did it, but they thought they knew all they wanted to know and more about biofilms and were ready to move on to a new topic. The actual class time spent on biofilms and microbiology was nine days except for taking the delayed posttest, but students seemed to mentally extend that time. The teacher-researcher's experience has shown that adolescents typically like to move on to new concepts and ideas.

Originally it was predicted that experiencing the science domain through cutting edge science and communication with biofilm researchers would engage the students and increase their motivation to study science. Because these strategies were narrow interventions a lack of observed changes in motivation to study science may not be surprising. The students who enjoyed the learning activities may be positively affected in the long-term though. The immediate effect was that the majority of the students were focused, interested, and wanted to do a good job.

## **Qualitative Data**

### **Overview**

The qualitative research component centered on the microbiology learning. The teacher-researcher was the measuring instrument and this study represents testing under best conditions; therefore, its intent was not to generalize the results to different populations (Gall et al, 1996, Patton, 1990; Miles & Huberman, 1994; and Tashakkori & Teddlie, 1998). Every attempt was made to reduce researcher bias and the reported data reflect openness in the student and teacher participant responses, the presence of unexpected actions and reactions, and both negative and positive responses. Triangulation was the major means of determining the quality and validity of the measurement. Triangulation of methods was accomplished by collecting both

quantitative and qualitative data. Triangulation of data sources occurred through observations, interviews, journal reflections, student evaluations, debriefing responses, and the final student products. The extensive collection of qualitative data was organized in figure 2, page 55 to show that the data described the relative contributions of the three instructional strategies to student understanding of biofilms and selected microbiology concepts. The teacher-researcher conducted an extensive content analysis of these observations and artifacts while periodically consulting with other education experts.

The careful and methodical observation of the present world of the students provided information rich data through qualitative analysis. The individuals being observed interacted with the participant observer and their responses were often in the form of dialogue between the observer and the observed. Both were at various times either on the sending or receiving end of information and their experiences were interwoven. Understanding of the group interactions emerged; however, ethnography was not a major focus of this study. There was evidence of shared meanings that contributed to the thick description of the relative contributions that each instructional strategy made to understanding microbiology and motivation in science. In a more general sense, it contributed to knowledge of how learners construct meanings and what types of instructional strategies engage them in learning. The context was greatly influenced by instructional strategies grounded in human constructivism and cognitive science and by the perspective of the teacher as participant observer in a naturalistic setting.

Rigorous methods of analysis evidenced by the careful and thorough recording of field notes, videotaping and transcription of interviews, and content analysis were used. Patterns were identified, coded and categorized using the QSM NUD\*IST™ (1997) computer software program. There was a strong agreement between several conceptual patterns and contextual relationships that emerged from the many data sources.

### **Changes in CAT Student Motivation**

#### **Long-Term**

The 12 female high school biology students (CAT) who taught the middle school students were asked to describe any changes in their interest in learning science that may have resulted from teaching the middle school students. Findings are mixed and represent the students' perceptions. Eight of the students reported no real change in interest with Lydia's response being, that she "... had fun. There's not really any changes. I didn't lessen my interest in science." Linda's response was, "If anything it increased it more. It made me think about teaching science. I'm going to go into something in the science field so it helped increase it." Three of the students did not talk about their interest directly but reported positive changes in their perception of learning in a metacognitive sense. One found that teaching the middle school students made her understand science better and want someone to explain it better to her when she was trying to learn something. Another mentioned that "middle school students learn visually too" and that one has to have "variety" in her teaching. Nancy stated that "I never really talked about it (science) before and I learned that that's fun to do and you can help them." Because these three students did not report a decrease or increase in

interest in science it was assumed that their interest did not change which correlated with the eight that actually reported no change. Generally, the CAT students maintained or increased their motivation to study science.

### **Short-Term**

The CAT students' reflections on why they wanted to teach the middle school students indicates that all but one were intrinsically motivated. That one student said that she wanted to do it because she would receive extra credit in science. But she also thought that it would be fun to do. Leslie responded in the interview that, "I thought it would be fun at first. And then I thought it would help me understand biofilms better. It would probably force me to learn it." Ellen answered in a similar way, "By doing that I would understand it more because I'd have to learn it and I'd have to get a little more into this." Susan said, "I thought it would be fun and it made me want to work harder. We were told that the best group would be going and I wanted to be that group."

Other observations support a change in motivation that was reflected in the CAT students' pride in their accomplishment of teaching the middle school students and in their level of self-confidence. The CAT students reported that they were "nervous," "excited," and "scared" before they taught and that they rehearsed ("go over it like I was talking to them") and made decisions about what teaching methods to use. All reported that the experience went well for them and the middle school students enjoyed it and learned a lot about biofilms.

All of the CAT students indicated that they were confident before they taught the middle school students because they had already presented it to their peers, had



studied it, had constructed the image product, and were older than they were. Most said that the middle school experience “boosted” their confidence; and even if they did not know everything about biofilms, they knew more than the middle school students. They received positive feedback from the middle school students when they answered questions about biofilms after the teaching. Michelle’s response was a typical one, “I think they learned something. They were having a conversation back and forth with us and talking.”

Every indication is that the CAT students were motivated to do a good job and to know enough about biofilms so that they could answer questions. They were rewarded by the middle school students’ apparent interest in what they were saying, the middle school students’ ability to understand them, and in the fact that the middle school students learned something about a topic that was unfamiliar to them. These short-term changes in motivation may have longer effects that could not be detected within the time frame of this research. It is also important to recognize that these teaching strategies made up only a small portion of the context of the biology course. All of these factors contribute to motivation and when a learning experience is pleasurable the effects can be long-term as well as short-term. It may be impossible to analyze their motivational effects separate from their larger context.

### **Instructional Strategy 1: Cutting Edge Science of Biofilm Research and Interactive Communication with Biofilm Researchers**

#### **Learning Environment**

These students were the ideal subjects. Their responses to open-ended question 1 on the pre-tests revealed that they had no prior knowledge of biofilms. Most

incorrectly thought that a biofilm was a movie about biology. Before the learning activities it was predicted that this novel topic would interest students in learning microbiology. The teacher-researcher also thought the students would be excited about being on the cutting edge in science and being able to experience science as it was developing. Prior teaching experience showed that students generally liked current events in science and were more aware of present happenings in science than historical events. Communicating with scientists and viewing the video would take students into the science domain and allow them to experience real cutting edge science.

The social setting that the female high school biology students constructed meanings in was not arbitrary but was purposively set up by the teachers to engage them in meaningful learning experiences. Appendix S shows that the learning environment successfully met most of the criteria for engaged learning (Jones, Valdez, Nowakowski, & Rasmussen, 1995) throughout the study. Some of these that were met included a) students taking responsibility for learning, b) collaboration, c) challenging, multi-disciplinary tasks, d) authentic ongoing assessment, e) an instructional model that was interactive, and f) cognitive, teaching, and product-based student roles. Students experienced the cutting edge science of biofilm research and communication with biofilm researchers in the context of this setting. How the students learned or did not learn was heavily influenced by it. Recorded observations of teacher-teacher, student-student, student-teacher, and student-researcher interactions revealed how cutting edge science and communications with biofilm researchers helped engage these students in learning.

An integral part of the learning environment was the ASM web site (<http://www.asmus.org>) where the biofilm imagebase was displayed. The decision to access this web site rather than use the CD-ROM was based on several factors as mentioned in the methods chapter of this dissertation. It is valuable to have learned from communications with ASM that even though the scientific community has indicated a desire to assist science educators their efforts may sometimes be much less effective than they could be. The planning and expense involved in producing a CD-ROM for high school science educators may be misapplied if it is randomly distributed in bulk to teachers without providing guidance in how to best use the product to facilitate science learning. Learning from this example, though the intent was to assist teachers, the scientific community's lack of understanding of how best to incorporate cutting edge science into a high school science curriculum may often result in the underutilization of quality resources. Because there were no records of actual teacher use an evaluation of the relative success of the CD-ROM could not be made. It is recommended that members of the scientific community and science educators collaborate to design and develop educational tools, field test their use in the science classroom, and evaluate their effectiveness prior to production and dissemination of these tools.

The teachers' directions and how they gave them also contributed to the learning environment and affected how the cutting edge science of biofilm research and communication with researchers engaged the students. Both teachers had a similar style of facilitating the project evidenced by giving verbal directions, moving from group to group, announcing the amount of class time and project time remaining, reminding

them of individual responsibilities, writing information on the board, referring to other web sites and resources, and encouraging participation. There were individual teacher differences in their prior knowledge of and interest in biofilms, in what they said, and what they expected from the students that appear to have affected the final biofilm image products.

### **Patterns of Engagement While Constructing Image Products**

Researcher observations, student responses during the debriefing, and student journal reflections revealed patterns in how the cutting edge biofilm research as revealed on the ASM website format facilitated or did not facilitate understanding for the female high school biology students. Images of biofilms have no meaning for those unfamiliar with them unless they are accompanied by explanatory text that is easy to understand and that fills in the gaps where no prior knowledge exists. Most students had no trouble finding enough information on the ASM site or used it as a springboard to other sites. In some cases though the explanations did not contribute to student understanding. When this happened the students tended to skip over the confusing information, became less engaged and did not ask for teacher assistance thus omitting its content from their projects. Students who were not effectively engaged during the project, may have been if the information had been presented more on the level of understanding of a high school student.

Often when students could not find enough information about their biofilm on the ASM site they ventured out on their own that resulted in their becoming more engaged. These solo journeys were not always successful though. Leslie reflected in her journal after being lost on the Internet, "Today we found a little bit of information

on our marine bioluminescent biofilm. We couldn't find very much and this is getting very aggravating." Mindy reported, "Today we looked on the Internet. Stress, stress, stress! We can't find anything on the ecosystems, it's so hard I hate it."

The general sequence of activities that the students participated in was to watch the video, explore the ASM site with its images, select a biofilm topic, research the topic, design the biofilm image product, construct the product, design a presentation, practice the presentation, and present the product to peers. Additionally, the cross-age teachers presented to the middle school students. Some groups followed additional steps in the sequence, for example, practicing their peer or CAT presentations.

The images presented in the video engaged the students immediately possibly because of their novelty as the students self reported a lack of prior knowledge about biofilms. Most of the students openly expressed excitement about learning about biofilms. The initial exploratory journey through the ASM imagebase increased the level of excitement. A pattern that emerged was that the students were initially most engaged when exploring biofilms that were already familiar to them such as dental biofilms. During the debriefing, dental plaque was most often rated the most interesting and the best liked project and there was a reluctance to explore the unknown. It was somewhat surprising that the students did not initially make the connection that these biofilms also affect them. Bioluminescence was rated the second most interesting and comments indicated that this was because "it glows." These findings support the National Science Education Standards (1996) recommendation that teachers present fewer topics but in more depth. Students need to be encouraged to go beyond their prior knowledge and experience new ideas. Biofilms may have been a hard topic to sell

the female high school students because they are often invisible and many types do not directly relate to the human body, which these students are naturally curious about.

A second pattern that emerged during the tour through the images was a tendency to focus on the negative aspects of bacteria and minimize their benefits to mankind. In general students self reported their prior knowledge of bacteria to be that they were "disgusting" and caused diseases. The more "disgusting" they were perceived to be the more they engaged the students. The students were openly energized and excited when learning about these biofilms. There was a fascination with how "gross" bacteria were and students had a tendency to sensationalize them. Darlene recorded in her journal:

Today we got into our groups and finished watching the video. Also we went to the website ([www.asmusa.org](http://www.asmusa.org)). There were so many pictures of biofilms. Looking at them was pretty neat, but when you think about those biofilms being around you sends a chill up your spine.

Though the main interest was the topic (type of biofilm), the types of images that were selected and the product designs were also indicators of engaged learning. The products that displayed more abstract concepts provided evidence of deeper understandings. There generally appeared to be no preference for color over black and white images though a couple of students said that they picked their topics because they liked the colors of the images. There appeared to be little interest in the technology used to produce the images. There was interest in what the images represented such as a *Listeria* group's "comet tails," an alpine biofilm group's close-up and far away perspectives, and a dental biofilm group's stages of development of dental plaque on teeth. Though students were instructed to explain the amount of magnification of the

images their microscopic size did not appear to amaze them. None of the groups used diagrams from the imagebase though some produced their own diagrams.

Most products represented various degrees of abstract thinking or "thinking out of the box," though there appeared to be a slight teacher difference because Teacher 2's students showed less creativity. More engaged students' initial explorations led them to think of ways to reorganize the images and the text material and subsequently edit and revise. Use of the image to construct a representation and to teach peers and/or middle school students was an authentic task that challenged the students to stretch their imaginations and make connections between the content and real life experiences.

### **Preconceptions of Communication With Biofilm Researchers**

The teacher-researcher made the initial assumption that E-mail addresses of scientists are placed on the Internet to enable the public to communicate with the scientist. It was thought that scientists need and want to be able to communicate with other scientists and the public about their areas of expertise. This and the fact that ASM and the Center for Biofilm Engineering both expressed an interest in making the public more aware of biofilms and microorganisms suggested that the students would be able to learn from biofilm researchers through communications with them. Students would be able to experience real cutting edge science through the scientists' lived experiences.

The Internet greatly increases public access to information and was readily accessible to the biology students. Technical problems at Millville Academy were few and far between and there was relatively consistent Internet access during the school day. Most students also had Internet access at home and the library's computer lab was

also open until 6:00 p.m. and this enabled students to follow up on assignments they did not complete in class. The teacher-researcher contacted the Operations Director at the Center and discussed the project with her and the possibility of students E-mailing scientists. The students were instructed to use proper etiquette, to identify themselves and the school, and to give the reason for their inquiries. The teachers also instructed the students to tell the scientists they contacted that they were working within a set time frame within which the project had to be completed.

Coordinating 19 groups' communications with mentors through E-mail was a new experience for the teachers and neither had participated in workshops or other professional development activities that taught how to do this. On the third day of the project students were told that they were expected to contact and communicate with a biofilm researcher in order to learn more about their specific biofilm and cutting edge biofilm research in general. The ASM web page, the Center's web page, and the University of Maryland Sea Grant web page were the first sources given to the students and served as jumping off points to other scientists. A Louisiana State University researcher who had a role in the instructional video also offered to help answer student questions. Teacher 2 referred students to the ASM site and gave instructions on how to contact a mentor:

At this point of the site (writes address on board) there's a selection that you can make that says request a scientist mentor. And it asks you to provide some information. You can't provide that information exactly on the little questionnaire there but you can scroll down to the bottom and it says to E-mail to a particular place. So, if you want to request a scientist mentor you can go and get some of this information on your biofilm from the scientist mentor through E-mail but you must tell these mentors what your time frame is and I'm going to tell you.



Capitalizing on the perceived expediency of E-mail, the teacher-researcher thought that three class days followed by a week-long school holiday would afford more than enough time to hear back from a biofilm researcher. The teacher-researcher's instructions illustrate what the students were told:

So go ahead and start your project, contacting your mentor. You need to start developing questions that you want to ask your mentor about it (the project). Find it (the image). See what information you already have. See what questions you can answer from the website. And then which ones are you going to need to ask the mentor for help with.

With this in mind most groups E-mailed several scientists.

### **Patterns of Engagement While Communicating**

Evidence of student engagement was gathered through teacher observations and journal reflections. Some groups were successful and received helpful replies within a couple of days; however, these were the exception. Most groups did not communicate with a researcher. Teacher 2's classes did not have any success with mentors and the teacher reported that no group received a reply. But as evidenced in her student Mindy's journal at least one group did not attempt to contact a mentor until the last day of the project. None of Teacher 2's groups kept copies of requests they sent to the researchers nor did they keep late replies that were received after the project deadline.

### **Student Requests**

For these reasons the documents that were examined were copies of E-mails sent and received by only the teacher-researcher's groups. The students asked for information in different ways. Types of requests were for information about the specific biofilm, for answers to specific questions, or where to find information. Most

did not sufficiently identify themselves or the reason for their request. A *Giardia lamblia* group sent an example of a request that was too general:

dear maddam (sic),  
We are 10<sup>th</sup> grade students from St. Joseph's Academy in Baton Rouge, Louisiana. We are currently conducting research on biofilms found in mouse intestines for a very important Biology project. Please reply as soon as possible if you could be of any help to us; we would greatly appreciate your assistance.

A dental biofilm student explained the reason for her request but failed to identify the group as being high school biology students. She wrote, " We are in need of a mentor for our project on dental plaque biofilms. Our project is teaching this subject to the other students. If you have any images, information, etc. on dental plaque biofilms please contact us."

The most demanding request was from Helen, a bioluminescent biofilm group member, who attached a list of 15 questions for the researcher to answer. Thirty-four student requests were examined and an additional eighteen were reportedly sent.

### **Researcher Responses**

There were seventeen responses from researchers (See Appendix T). The responses were varied and included a) web addresses, b) journal citations, c) journal abstracts, d) references to texts, journals, and encyclopedias, e) E-mail addresses of other researchers, and f) an acknowledgement of the request and forwarding to a graduate student. When the students asked for biofilm information they most often hit a dead end. Dead ends were in the form of no response or a response that did not provide assistance. Dead ends frustrated the students and had a strongly negative effect on them. The most common description of the experience, as reported during the debriefing, was that communicating with scientists was not helpful because they never

wrote back. Typically students gave up and referred to the researchers as being "too busy," "too important," and "rude." One student wrote, "I would feel too stupid because scientists are smart and I'm not." Figure 5 illustrates the sequence of events that occurred in the sending and receiving of messages.

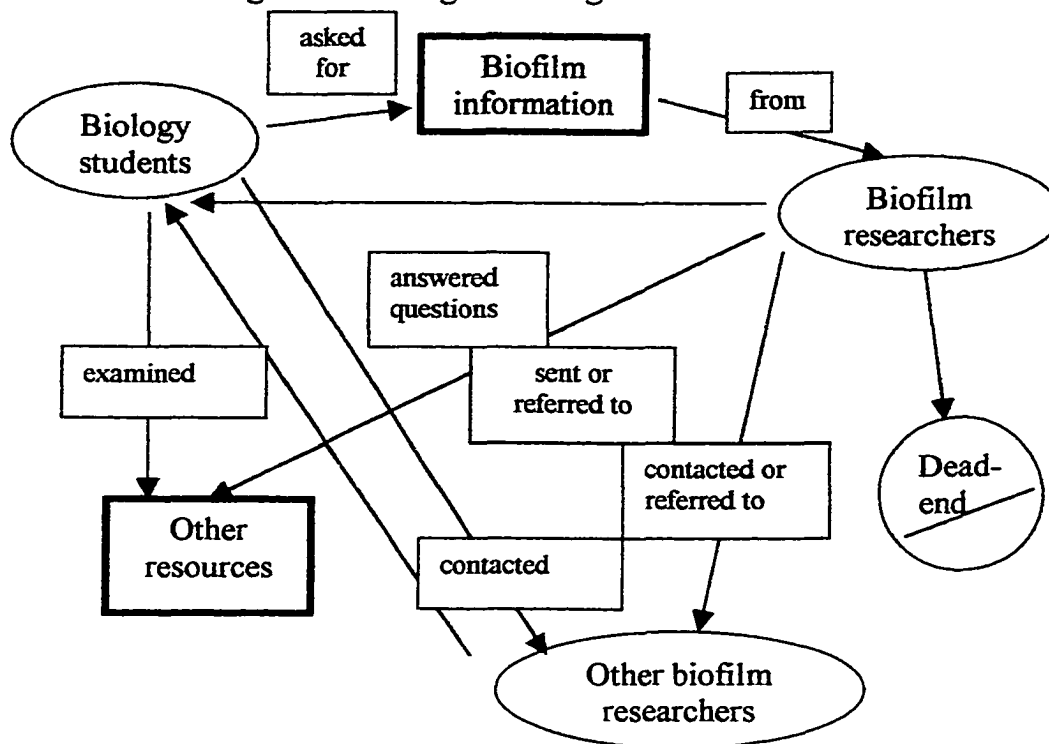


Figure 5. Sequence of E-mail Communications Between Female High School Biology Students and Biofilm Researchers

In contrast positive responses that rewarded the students' efforts were uplifting and energized the students. They excitedly reported to the class that their mentor had E-mailed them back. They reported during the debriefing that it was easy to communicate with a scientist. One response was, "It's easier to talk to them through E-mails because you get a chance to say what you need to get said without any interruptions." And as another student wrote, "It was easy because you could talk to a person and learn better than just reading information."

Researchers were most often associated with universities including Stanford University, University of California Berkeley, Ben-Gurion University of the Negev (Israel), Iowa State University, Louisiana State University, University of Virginia Health System, Oklahoma State University, and Washington State University. Other respondents were from the Center for Biofilm Engineering, ASM, Brookhaven National Laboratories, and the Maryland Sea Grant Extension Program. Most researchers who responded offered words of encouragement including "Neat project," "Happy Hunting," "Good Luck," "I would be happy to assist you...", and "Hope this helps you and your classmates." One individual no longer conducted research but worked as an editor and writer at home. She offered to edit the student's writing or assist her in research on the Internet. The teacher participants had also instructed the students to ask the researcher about his or her work. Fred, who answered two E-mail requests, described his work as a research associate at the Center as being "enviable" and "very satisfying." He wrote:

I have a PhD in chemistry (organic chemistry), but have been working in the environmental field for many years. I design and work with microelectrodes. Microelectrodes are small electro-chemical probes that measure chemical species in biofilms. They are thinner than a human hair, and can be inserted in biofilms to measure how fast the bacteria use oxygen and nutrients....

I decided that I was interested in electronics, instrumentation, and computers many years ago, so I taught myself these disciplines. I hope I never stop learning.

A researcher at the Center who had been contacted by the teacher-researcher prior to the students' requests responded to one student, "Your questions are good and interesting; however, the key to research is to be able to find the answers yourself and not to have someone give them to you. I will point you in some directions." The web addresses she

listed included the Center's address and that of a meta search engine. This type of response was demoralizing to the students and sort of let the air out of their sails. The student who happened to be a lower ability student interpreted these comments as being demeaning and wanted to give up trying to contact a biofilm researcher. Later this same scientist who also played a role in the video, E-mailed the teacher-researcher the following:

It is a great idea to have students communicate with scientists, however we should be told in advance that we will be receiving E-mails from several students. I was under the impression that these were students who were trying to get answers to a research project without doing the research work. It would be helpful in the future if you could ask someone (or several people) to serve as a resource person and to let us know what type of information you would like them to provide. One student e-mailed me on Monday and asked that I give her the answers by Wednesday. This may not be enough time to provide all of the information the student seeks. We do not have all the answers at our disposal and many of the answers that the student seeks requires a little research on our end. In addition, to know a little about the student and their knowledge of biology will help us give appropriate answers. To all of the questions that I have received I would be able to write several different responses, varying in complexity, depending upon the reader.

Primarily what I ask is that you, or your colleagues, contact a specific person to be your mentor for these students. It is important that we are prewarned of the questions that they will be asking. Our time is limited here and although we want to help everyone learn more about biofilms I really can not commit the amount of time needed on such short notice. In the future, please contact one of us at the CBE well in advance of your student's requests for information.

Please keep in touch.

The content of this E-mail was basically the same as that discussed in a phone conversation later the same day and frustrated the teacher-researcher. It appeared that the students were correct in saying that scientists are too busy to dialogue with them and share their experiences.

An example that strongly contrasts with this response is the one that a researcher from the Maryland Sea Grant Extension Program sent to Helen. These types of responses suggest that some scientists are willing to collaborate with high school students and encourage further study of how to form working relationships with them. In it he briefly answered all 15 of her questions and referred her to a lesson on the program's web site for more in depth information. Even though Helen did not provide any specifics about the project, "My biology class is doing a project. We are learning about biofilms, " Anthony started off his reply with, "Neat project." These types of communications, though few, engaged the students, got them excited about science, and helped them understand biofilms and microbiology concepts.

### **Summary**

In summary, interactive communication with biofilm researchers produced mixed findings. The limited number of scientist responses to the students indicates that the scientific community as a whole may not be committed to assisting in the improvement of science education at the high school level. Because E-mail facilitates communication, the biofilm researchers could have quickly responded even if they were not able to help the students. A response indicating that they would like to help but were unable to would probably not have offended the students as much as the total lack of response did. No response at all did not encourage student interest in biofilms, microbiology, or science. The students were stimulated by responses that assisted them in some way even if it meant referring them to other researchers. Every researcher who responded offered words of encouragement and expressed interest in the students' biofilm image product.

Another important finding is that the students need direction in how to structure their requests for information and who to contact. As Morrison and Collins (1996) have found students, teachers, and scientists may be trying to communicate without having epistemic fluency in each other's domains. Expressions and meanings that make up dialogue are heavily influenced by the culture within which one works. This study found that science teachers need experience in how to facilitate the interactions and thinking about epistemic fluency should improve the teacher's ability to facilitate. This teacher-researcher's experiences have found that demands on teachers and their time are already so great that they may be reluctant to try new strategies, such as interactive communication with researchers, unless they have specific guidelines for doing so. Teachers also need to plan well ahead of the communication activity so that "dead ends" can be circumvented. The study indicates that if more time is allowed for the communication there may be more successful matches between students and scientists.

It is thought that this interactive communication with science researchers could greatly contribute to meaningful learning and increase student interest and motivation in science. Ways to facilitate these interactive communications should be studied further and should be a cooperative effort between the scientific community and high school science educators. Experiencing cutting edge science through communication with a science researcher is a resource that has tremendous potential and would benefit both the scientist and the student.

## **Instructional Strategy 2: CAT Adaptations of an Instructional Video**

### **Preconceptions About A Biofilm's Bio**

The teachers' adaptations of A Biofilm's Bio affected how the female high school biology students progressed toward meaningful microbiological learning. Subsequent use of the video by the CAT students to teach the middle school students was influenced by the CAT students' learning experiences with it. The teachers used the video to introduce the topic of biofilms to the high school students. In fact, for Teacher 2 who was initially unfamiliar with biofilms, this was one of her major resources for information. The teacher participants verbalized a strong connection between the video and learning about biofilms, ecology, and microbiology. They frequently made reference to information in the video during class discussion of the biofilm image project as when Teacher 2 said, "Remember in the video when they talked about..." The CAT students imitated the teachers when they adapted the video for teaching the middle school students.

### **All Students**

NCAT students did not use the video to teach the middle school students; however, both NCAT and CAT student journal reflections gave some indication of how it affected their progress toward meaningful microbiological learning. The effect that the video had on the students was mixed. Most students indicated in journal entry 1 that they understood what a biofilm was after watching the video and participating in a class discussion. However, Laura thought that the teacher's adaptation of the video was not necessarily the best way for her to learn. She revealed that, "Today we continued with the video. It is very interesting, but they talk a little fast for us to catch on. It is very



well put together and you learn well from it. I think we should maybe watch the video and then take notes because it is hard to stop and take notes." Diane disagreed. "Today we watched more of the video. It's really neat, and I am learning lots of new information. I like this way of learning. It's slower, and more visual rather than just taking notes." In contrast, Leslie (NCAT) wrote, "Today we watched the film on biofilms. I still don't understand exactly what they are. The film was good, but it moved too fast with too much information." Interestingly no one asked to view the video again whether as preparation for teaching the middle school students or to review concepts on their own.

Student responses during the debriefing provided further insight into what they thought about its quality and its usefulness as a learning tool to facilitate meaningful learning. One must be mindful that student perceptions were also influenced by any prior learning experiences they had with videos in the past. The quality of the video received mixed reviews from the students. When asked what they would change about the video the responded "do not remember it," "nothing (The movie was cool)," "less background music," "do not stop it every two seconds; see it the whole way through," "kinda corny, immature, elementary, dorky, boring." The majority response was that it needed to be slowed down. The evaluation of the video as an effective learning tool also revealed a dichotomy in student perceptions. Most thought that it helped give the "big picture" and an "introduction" or a "pretty good base for learning about biofilms." An exception was one student's response that it was not helpful because "we watched it before we knew anything about biofilms," missing the fact that it was shown to

introduce students to the concept of biofilms, biofilm technology, and how scientists work.

During the peer teaching part of the project, there was evidence that all students mentally adapted the video though none of the groups used the actual video in whole or part as a teaching tool. They made frequent references to the characteristics of biofilms that were presented in the video. Students were told that groups would be selected to teach the middle school students. Even though 23 female high school biology students actually taught the middle school students, all of the peer presentations were influenced by the prospect. All of the groups planned their presentations around teaching them. One group even said that they taught their peers as if they were the middle school students.

Several of the groups reinforced concepts presented in the video when they taught their peers though no direct reference was made to the video. There was evidence of understanding as most groups connected general understandings about biofilms to their specific biofilms. They described the general characteristics of biofilms and then pointed out specific characteristics of their biofilm, in a sequential order similar to that of the video. A dental plaque group lifted specific examples of biofilms from the video and incorporated them into its presentation.

These are some examples of where they're found. If you haven't noticed, this is supposed to be a Fido's dog bowl. And they're found in a vase. It would be on a film and like slimy and stuff. This is a mascara wand and that's pretty disgusting because you're like putting it back on your eye and all. Gym sock and in your refrigerator.

### **CAT Students**

Cross Age Teachers (CAT) adapted the video for teaching the middle school students. These students, though they had not seen the video in four months, did not ask to review it prior to teaching. Teacher instructions (Appendix D) suggested that they use the video to introduce biofilms and pause when needed for discussion with the middle school students. The three groups that were studied in depth demonstrate observed patterns in progress in meaningful microbiological learning. The Plant Root Biofilm Group, the Dental Plaque Group, and the Contact Lens Biofilm Group represent how the video was adapted. They showed the video first to introduce the students to the biofilm concept and the general characteristics of biofilms. They paused the video four or five times, after main idea sections, and engaged the middle school students in a question and answer discussion. Only one group did this differently. One dental plaque group began the same way but stopped the video after the visit to the dentist and presented its project. Then it finished showing the video and concluded with a question and answer session.

The general pattern was to pause and tie new information back to the initial more general information about biofilms presented at the beginning of the video. The natural pauses occurred after explanations of what a biofilm is, what biofilms need to live and grow, descriptions of the environments that biofilms grow in, and finally how biofilms are helpful or harmful. The students were able to explain new terms as they used them in context. Their explanations were usually simple but accurate and included ecology, polysaccharide matrix, biobarrier, community, population, bioprospecting,

ecosystem, and extreme environments. An exception to this pattern occurred when one student inappropriately explained bioprospecting as the ability of biofilms to live at extreme environments. Only one group engaged the students in attempting to answer the challenge question on the video.

During the CAT interviews the students were asked to describe what they considered to be strengths in their presentations to the middle school students. Surprisingly the biofilm technologies described in the videos failed to captivate their interest and were rarely mentioned. Even the trip to Yellowstone that took an entire day of shooting was only recalled by one student. Five of the 12 students considered the video to be a strong point. One student thought that it helped fill in gaps in information that the group did not provide because, "It helped us in case we forgot something. We could always refer to the video." Another student thought that the group filled in the gaps of the video. When asked about the strong point of the presentation, "I'd have to say when we were doing the movie. We'd stop it and then we'd talk to them about it. It kind of led them. If they didn't understand it, we'd explain to them along the way."

### **Instructional Strategy 3: Cross Age Teaching**

There was evidence that teacher directions influenced the final product. Teacher 2 implored the students to, " Pick the image that you like the best and that the group agrees on to do a presentation. It's easiest to make it the most interesting." The directions were flexible and emerged as students offered input. On the second day students were encouraged to freely explore the site and construct their project. Both teachers used the examples of a PowerPoint presentation and a diorama when describing ways to use the biofilm images. Teacher 2 also suggested a poster while the

teacher-researcher did not but suggested a 3D-model. The teacher-researcher prompted the students with "....there are lots of things you can do" and later that period, "I want you to see where your imagination will take you."

Together the teachers and students brainstormed the criteria for the project and the grading rubric:

Teacher 2: If you had to prepare a presentation on one image, on one biofilm, what kind of information would be essential for you to include in your presentation so that the people in your audience would know exactly what you're talking about and come away with a great understanding of what the biofilm was?

The teacher wrote these on the board and the researcher later compiled the responses from all of the classes and provided each student with a project checklist. (Appendix U). There was a great deal of consistency between the lists that each class generated. The checklist included (a) types of biofilms, (b) where they are found, (c) their effects, and (d) how they grow. The teachers guided the students towards thinking about ideas such as their scientific names, how they interact with their environment, and how the image was taken.

### **Preconceptions of Image Use**

The web based ASM biofilm imagebase was used after careful scrutiny and evaluation by the teacher-researcher indicated that its use would engage the biology students in learning. . The checklist shown in Appendix X provides an overview of the evaluation of the imagebase. The criteria include the biofilm type, image type, relevance to students, perceived quality, and how the image can be used by students. The teacher-researcher considered the imagebase to be an excellent effort by the scientific community to make valid information available to teachers and students. To

insure a high degree of scientific quality, the images were subjected to peer review and represented contributions from scientists around the world. Prior to student exploration of the imagebase, the teacher-researcher thought that the number of digitized images, the variety of types, their relevance to students, and their ability to accurately illustrate scientific concepts would facilitate the female high school biology students' understandings of selected microbiology and ecology concepts and interest them in learning. The design and layout of the web site made it easy to navigate the imagebase. It was also thought that the teachers' and students' advanced skill levels and experience with word processing, presentation software, and Internet access would enable the students to be creative and use the images in novel ways.

The summary text descriptions and explanations that accompanied the images seemed to be of appropriate length for high school students. General information about biofilms and their importance was combined with more specific information about selected biofilms grouped into categories of medical/dental, environmental, and industrial biofilms. The content level was deemed appropriate for teaching high school biology students about biofilms and microbiology. A teacher-researcher anticipated drawback was that even though there was an excellent glossary, the language was sometimes too difficult for high school students taking their first biology class to understand. Sometimes complex or unfamiliar terms were defined and not explained well in context so students could make connections between them.

### **Student Selection of Biofilm Images**

When exploring the ASM web site and biofilm imagebase for the first time students worked on laptop computers individually or in pairs while in their cooperative

groups. Their binders were open as they recorded information that they found. They moved freely about the room sharing experiences, and reacting to the images both verbally and through body language. Which images were they most attracted to? The students clicked on the medical/dental biofilm category first. Initially they were most interested in dental plaque and spent more time exploring it. Dental biofilms was the topic that was selected first in every class. There was a sense of urgency in selecting this topic and getting it before anyone else did.

The students often sensationalized the image subject. The image that elicited the strongest reaction in every class was a photograph of a person's teeth with iodophilic polysaccharide in the dental plaque stained red by a dye. The students would be quietly navigating the imagebase and suddenly someone would exclaim, "Oh gross!" and other students would rush over and ask about it. The image discoverer would have to explain how to find the image to the rest of the students. As the level of excitement increased, the students' dialogues became louder. In one particular case a student adapted the teeth image by copying and pasting it to the background (wallpaper) on her computer. The other students immediately were interested in the image as evidenced by one student's exclamation, "Ooh, that is so gross!" Sometimes the students expressed their disgust by giggling. One student put her hands over her eyes while another shrugged her shoulders and shook her body. Students asked questions and called the teacher over to take a look. The students were energized and shared their discoveries verbally with the whole class. The group leaders kept the students on task and only rarely did the entire group get off task. There were a few individuals who were

observed doing nothing, wandering aimlessly, or doing other things; but, as the time for project completion got closer, there was less and less off task behavior.

### **Student Perceptions**

Journal reflections and thoughts recorded during the final debriefing corroborated the patterns in learning and motivation observed by the teacher-researcher. Though all of the journals were examined, three student journals from each teacher's class were randomly selected and analyzed for contextual patterns. In general, a journal reflection began by the student reporting what was experienced that day in class and/or what was learned. Often the student also expressed her perception of how things were going with the project. And most students described an initial interest in the project and anticipation of the learning experience. Most students indicated that they thought the project would be exciting and fun, but a lot of work. Darlene illustrates a typical perception of the first day:

I think that this biofilm project is going to be fun and interesting. But I think it will be a lot of hard work. I'm excited that we will be learning lots of new information that I never heard of before.

By the second day, the students had finished viewing the video and there was evidence that most were beginning to connect biofilms to their prior knowledge and personal experiences. One student liked to study about germs and bacteria on humans but not environmental biofilms; and Linda said, "Right now a biofilm seems to be no different than any other living cell."

Exceptions to the norm are represented by Diane who was not interested in biofilms at all at the beginning of the project. Throughout the project she repeatedly stated that she did not like the project and that what she liked was her group. However,



on the day that the ASM web site was first explored she wrote, " Today our group went to the website [www.asmus.org](http://www.asmus.org) and researched. We looked at the biofilm image. I'm becoming more interested in biofilms." Illustrating more student reactions to the images was their fascination with the bioluminescent marine bacteria that are "really pretty and glows" and "look really cool in the pictures."

Students also expressed their perceptions of how the images contributed to their understanding of biofilms and microbiology in their written responses to the debriefing question. This allowed the students to look back on the experience and the researcher gained more insight into how engaged they were at the time. In general they reported that the information was not very easy to understand. Student comments about their quality were that some were more helpful than others and that they were "too small," "not labeled," or "blurry." Most, however, said that they were very helpful. One student referred to them as being the only thing she understood. Several wrote about being visual learners and how it helped to get a "picture image in mind" and "see" how and where they (biofilms) lived. Again the fascination with bioluminescent biofilms was mentioned several times.

When asked what they would change about the ASM online images and information the responses varied and most thought nothing needed to be changed. Suggestions included a) get some good images of bioluminescent biofilms, b) have a bigger variety of pictures and information, c) have more information about biofilms, d) make them bigger, e) make them easier to obtain, f) tell how all the pictures were taken, and g) make it more of a fun site.

### **Student Use of Biofilm Images in Peer Teaching**

As students explored the imagebase they were observed selecting and saving the images, enlarging the images, and transferring the images. Students were able to easily and quickly copy and paste the online images into different formats such as Microsoft PowerPoint. This gave the students more control over their final biofilm image product. Students were observed asking the teachers questions about content but not about how to manipulate the images. A dental biofilm group member asked, "How can we make food chains plaque?" This typical question was interpreted as trying to find out how the bacteria in dental plaque fit into a food chain.

A great amount of talk was about how to get the job done, including the logistics of who was bringing what supplies and when, whether they would finish in time, and whether they needed to meet outside of class. But several groups showed evidence of more abstract thinking or thinking outside the box. The bioluminescent biofilm groups brought black lights and went into the closets (the darkest places) to test their glow in the dark paint. One dental plaque group asked their peers, "Who has eaten lunch and wants to donate plaque?" This group then spent most of the class time getting volunteers to scrape their teeth and smear it onto a microscope slide. The self-appointed group member in charge pursued the teacher and asked for a stain to use. They also asked for the microscope to be connected to the camera and TV monitor so they could see if it would enhance their presentation. A plant root biofilm group in another class also made microscope slides. They brought in their own specimen, a dead rose in a vase. Both groups spent most of a class period examining their slides under

the microscope. Others searched other web sites on their own and found additional information and/or images.

When groups constructed their biofilm image products, there were two categories of image use: replicating images and adapting images. Replicating images entailed simply copying and/or enlarging and then displaying the image on a flat surface such as poster board or poster paper. Groups adapting images used them in several novel ways including a) a diorama, b) a 3-D model of the image, c) a ready made model of its environment, d) a model that contained the replicated image, e) a student-drawn and colored representation of the image, or f) a student-drawn representation of the actual biofilm as seen under the microscope. The majority of the visual representations (nine) had a copy of the image pasted onto poster board, poster paper, or a three-panel display board. Six used a PowerPoint slide presentation, alone or in combination with posters. Only one of the PowerPoint groups combined animation and sound with the slides. Five groups used student constructed 3-D models alone or in combination with posters.

Though some groups simply pasted an isolated image onto poster board most groups used the images in context to depict where the biofilm grows. A *Listeria monocytogenes* group constructed a refrigerator 30 inches tall by 10 inches deep out of white foam board. The hinged door opened by a handle to reveal two shelves filled with various food containers and plastic fruits and vegetables. The inside of the door was lined with cloth material designed with a cowhide pattern. An enlarged black and white scanning electron microscopic image of the food borne pathogen *Listeria* covered a rectangular box that was glued inside the door making the image 3-D. Another

project consisted of a mouse intestine represented by 3 X 3 foot box with a small window cut into one side. Looking into the window revealed aluminum foil models of *Giardia lamblia* hanging from its inner wall and an enlarged ASM image. To illustrate bioluminescent marine biofilms a group glued the ASM biofilm image onto a large sheet of green poster paper that had been cut into the shape of a fish. The image was painted with luminescent paint so that it glowed in a darkened room when a black light was shone on it.

A *Listeria monocytogenes* product is an exemplary example of demonstrating biofilms in context. Four sheets of yellow poster paper formed the background. Sheet one was the title page and had large letters spelling out the name of the biofilm on it that were easy to read from a distance. A variety of images with legends underneath them were on the next two sheets. There was a black and white SEM image of rod-shaped *Listeria* biofilm attached to a steel surface. A few isolated cells were scattered away from the biofilm. There were color images of *Listeria* spreading from cell to cell and time-lapsed micrographs showing its comet tail shapes as it moved. The final image was a diagram with the message "Keep Food Safe From Bacteria" and the words "Clean, Separate, Cook, and Chill." A 3-D model interpretation of *Listeria* on stainless steel made out of rod-shaped candy was glued onto the fourth sheet. The sequence of the images, the limited use of words, and the variety of images gave a powerful explanation of what biofilms are. At the other extreme, a dental biofilm group sequentially presented 10 posters of text with a few scattered drawings and used only one ASM image.

Differences between the two teacher's classes were observed. Teacher 2's students had been instructed to select the best ASM image of their biofilm and most of the groups used only one replica of that image glued onto poster board. When more than one poster was used the remaining posters contained mainly written descriptions. One group did not even use the image. The teacher-researcher's produced a greater variety of products. The teacher's mastery of biofilm content knowledge and her comfort with instructional innovation appear to be key factors in successful implementation.

### **CAT Use of Biofilm Images**

The three middle school teachers were present when the CAT students taught their classes. Interview questions were mailed to the middle school teachers who reflected on the CAT teaching experience and returned written responses to the researcher. Each teacher thought that the CAT experience was a good one, partly because the middle school students' interest afterwards ranged from "moderately interested" to "very interested". For weeks after the experience middle school students would point out "slimy things " (biofilms) on the school grounds and call the teacher over to look. Importantly, the teachers reported that before the experience neither the teachers nor the middle school students had any knowledge of biofilms. Afterwards they had a "beginners knowledge of biofilms."

The middle school teachers described the levels of understanding that the high school students appeared to have. From their viewpoint the CAT students had a basic to good understanding of biofilms. They could not always answer questions about biofilms that the middle school students asked. Sometimes it seemed that they had memorized the information about biofilms but had not "internalized" it. In relation to cell structure

and bacteria one teacher wrote, "They had forgotten some of the basic terminology about cell structure, but you could tell they had studied it and they quickly remembered it when prompted." The teachers rated the CAT students' understanding of ecology highest.

They reported the strengths of the presentations to be the students' enthusiasm and ability to interact with the middle school students and the video. Some of the visual representations were more effective but overall they were also strengths. Being able to give examples that middle school students could relate to was a strength. But, in contrast, a perceived weakness was the inability to give novel examples of biofilms in their lives.

Transcribed videotapes of the CAT teaching also provided a rich description of the process. In the actual teaching all of the biofilm groups showed the video as previously described. A general pattern of how they used their biofilm image product to teach emerged and one of the dental biofilm group presentations is a representative example. Groups focused on their specific biofilms and spent more time talking about them. However they repeatedly referred back to general information about biofilms to reinforce the concept of biofilms. The dental biofilm group's explained, "And your mouth and your teeth are a perfect growing place for biofilms. Like the video said it's wet, it's a hard surface, and it's open to oxygen. You know when you breathe oxygen it gets in your mouth. It's a perfect place for them to grow."

The groups appeared to be comfortable with the role of teacher and orchestrated dialogue with the middle school students rather than lecturing. The dental biofilm group's over dependence on note cards was an exception. Only two of the groups wrote

terms on the blackboard where the students could visualize them. Groups often used self-constructed analogies to clarify their explanations. A dental biofilm student said, "A community is a collection of interacting populations. An example would be like your neighborhood. That's a community. It's different with biofilms cause, instead of people in the community, it would be microorganisms." They also stressed that biofilms are relevant to middle school students. They explained that biofilms had similar needs as humans do. The contact lens group stopped the video and said, "Now they just tell us the things that biofilms need to live and grow. Probably some of the things that humans need. Like we need oxygen. We need places to live." One perceived drawback was that they seemed to have an over reliance on biofilms that are relevant to the students' lives and often neglected to include new perspectives on biofilms.

Each group used their visuals such as a dead flower in a vase, toothbrushes, models, posters, and PowerPoint slides to facilitate the middle school students' visualization of more abstract concepts. A student in the dental biofilm group refers to a series of photographs illustrating the progressive build up of plaque with, "And these pictures, they show the different stages; like slightly and then really heavy and it's all by your gum line."

A student describes images of a plant root biofilm. She holds up the vase and images to show them.

When you leave them in water they get green slimy stuff on the bottom. Remember the word, 'polysaccharide matrix'? These are like magnified. ...It shows these little dots. That is the bacteria. The hairs are the hairs on the root. This is where the water is and it needs oxygen. This is the root hair and bacteria are the green dots everywhere. This is the fungal filament and the bacteria are

the orange dots. And this is our biofilm that we looked at under the microscope (student drawing). This is what it looked like to us.

An interesting conceptual pattern was the tendency to over emphasize the harmful effects of biofilms and downplay their benefits. Cleaning up oil spills was the only example of helpful uses of biofilms even though both the video and the ASM web page gave other examples. In conjunction with harmful effects, CAT students frequently used sensationalism and scare tactics to make their point. Comments from the biofilm group included, "This poster... Your parents are always telling you to brush your teeth. It's really important cause if you don't your teeth can really end up looking like this because this person had biofilm in her mouth. It formed dental plaque and it eroded their teeth and made them soft and broke them down like the video said. This is a normal kid too. All they did is stain his teeth." Another student reflected that, "I think they were really interested cause it was more about them. They had a chance of having biofilms in their mouth. They were more interested. I'd be scared if I were younger."

### **Progress Toward Understanding and Changes in Motivation**

Data in the quantitative section showed that the CAT students showed a larger increase in percentage correct on the open-ended response section of the posttest. As a culminating activity the CAT students co-constructed concept maps during clinical interviews with the teacher-researcher. Questions that were asked during the interviews are shown in Appendix W. These concept maps yielded data about the students' understandings about biofilms and microbiology in the context of ecology. They were evaluated using a standard concept map check list (Wandersee 1990). The average score was 8.8 indicating an above average level of understanding. Almost all



of the concept maps contained the basic concepts of location, requirements for life (needs), types, composition, ecology, and helpful/harmful effects. There was a shortage of novel examples as most gave examples from the video or from the imagebase. Though most of the CAT students remembered that biofilms can be helpful, only half showed evidence of understanding how they are helpful. Only one student elaborated on the polysaccharide matrix and described its composition (sticky sugar) and use (attachment and protection).

Figure 6 demonstrates the lowest level of understanding that was observed. There are no cross links between concepts indicating that the student did not understand that what a biofilm needs to live affects where it can grow. When a student can make this kind of connection on her own more meaningful learning has taken place. The only examples of biofilms that this student gave were aquatic biofilms and dental plaque. The topic, aquatic biofilms, was her group presentation and dental plaque was the one that the students had more prior knowledge about. If she had been able to list some of the more novel examples of biofilms her understanding would have been considered to be on a higher level. Her ability to list only five concepts related to biofilms also indicates limited but a basic understanding. Because of these combined factors this concept map was rated low on scientific quality. A comparison of figure 5 and figure 6 indicates that even though the CAT students seemed to have a better understanding of biofilms and selected microbiology concepts there are individual differences in the level of understanding and the ability to use a concept map to make connections between concepts

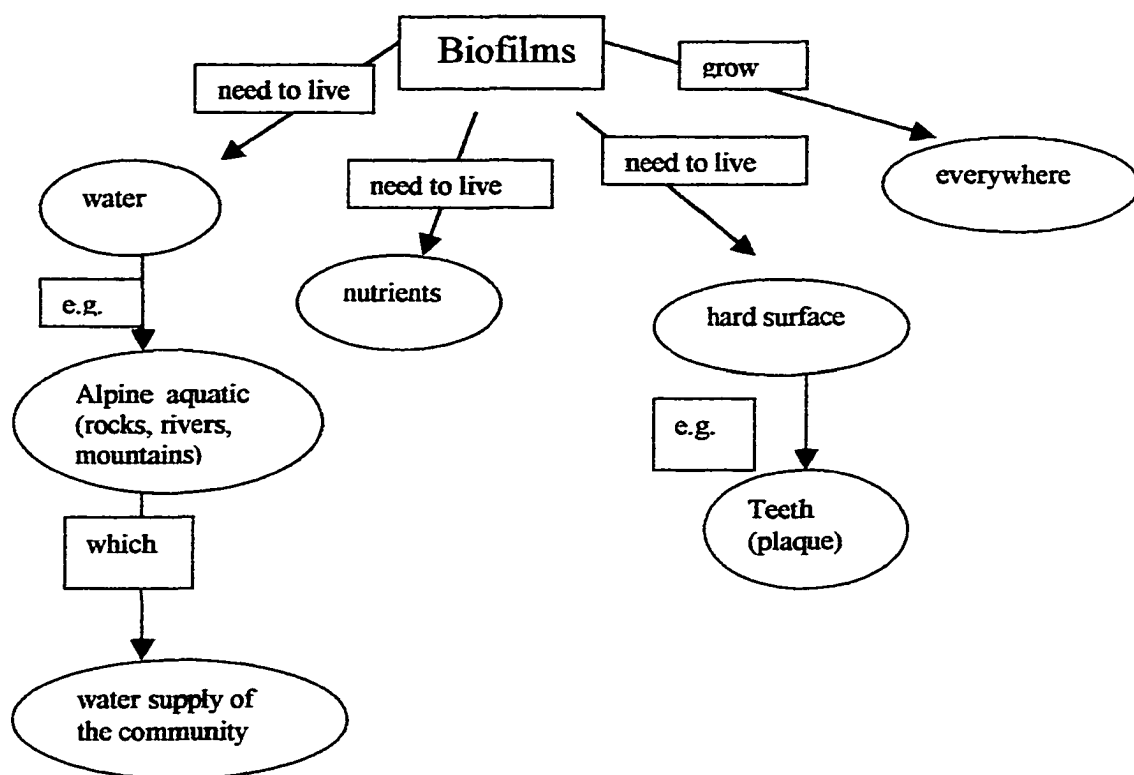


Figure 6. Example of CAT Student Concept Map That Shows Low Level of Understanding

In contrast, Figure 7 is representative of the highest level of understanding or more meaningful learning. This student was able to give several examples of biofilms, several of which were novel to her. These included rocks, intestine walls, fish, mouth and teeth. She made several connections between concepts as evidenced by labeled cross links and understands the bigger picture of biofilms interacting with other organisms and the environment. This concept map is typical of most of the ones constructed by CAT teachers. This student shows an understanding of how biofilms can be harmful and helpful. She even examines the organisms on a cellular level when she mentions their cell wall. There is slight confusion over just which organisms lack a nucleus but she does include bacteria as being one type. This concept map makes a

strong connection between what biofilms need to live and the fact that they grow where these factors are present.

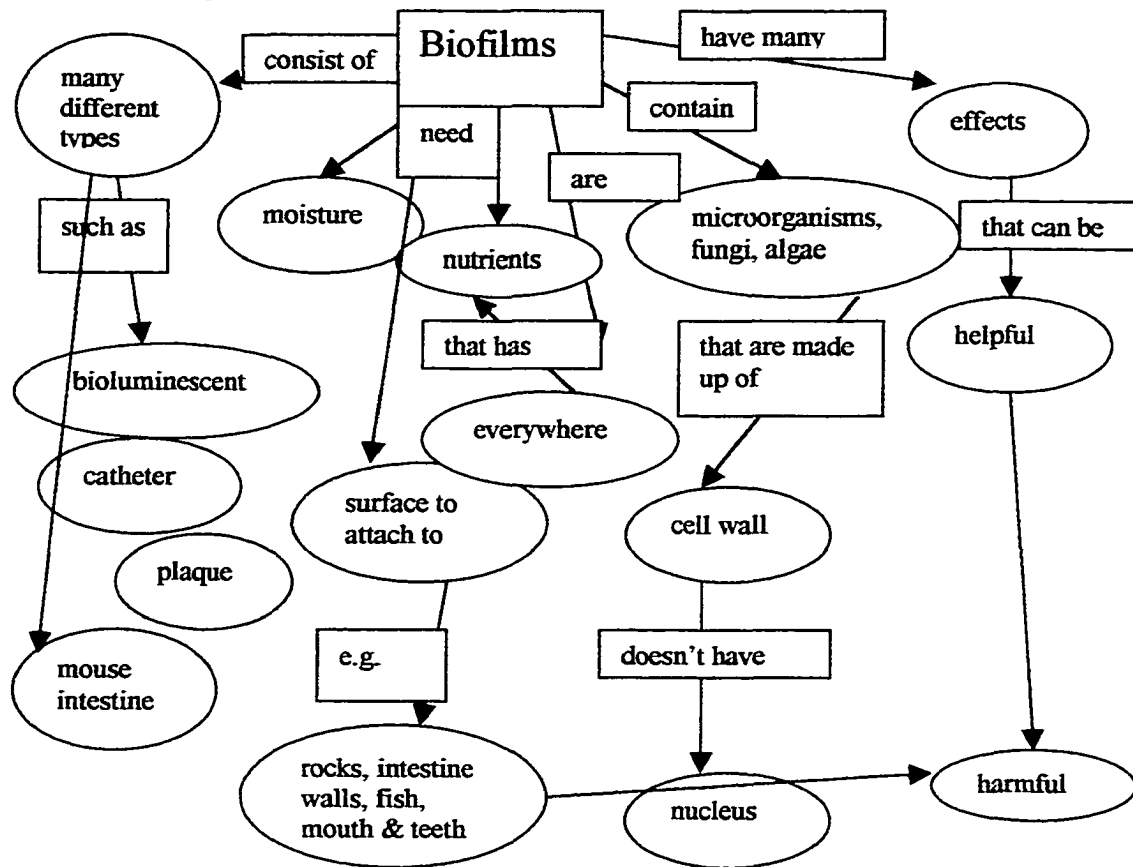


Figure 7. Example of CAT Concept Map That Shows High Level of Understanding

### Summary

The conditions of Millville Academy may be in conflict with the findings of some researchers of gender equity in science education (Kahle, 1992). Though there may be some underachievement in science, these female biology students generally are motivated to improve and the differences that were observed in mixed gender classrooms do not enter into this study. Their overall interest in learning science represents an atypical example.

The findings of this study support Ausubel's meaningful learning theory (Ausubel, et al. 1978). When students could connect their experiences to prior knowledge they developed deeper understandings. The students developed deeper understandings of the dental biofilms that they were more familiar with and had some prior knowledge of. A combination of rote and more reflective learning took place and increased understandings of biofilms and microbiology. Paivio's DCT was supported when the students learned through the video presentation and the imagebase. The CAT teachers even said that their students learned "visually" from their own image products. Ponzio's (1998) findings that adolescents can successfully teach younger students in informal educational settings such as 4-H Club and learn while they teach were supported and extended to formal educational settings in this study. This study also supports heterogeneous grouping for cooperative learning (Doran, Chan & Tamir, 1999), however, only if the groups are closely monitored by the teacher.

Typical patterns were (a) increased interest in relevant biofilms with dental biofilms rating number one, (b) use of novel adaptations of the biofilm images with some atypical cases, (c) noncreative adaptation of the instructional video for teaching the middle school students, (c) sensationalism of various biofilms, (d) a tendency to emphasize the negative effects of bacteria even though they were exposed to modern technological uses, (e) unsuccessful attempts to communicate with biofilm researchers, (f) positive feedback from biofilm researchers who did communicate (with one exception), and (g) increased understanding by CAT students who taught the middle school students.

The guidelines set forth in the National Science Education Standards (NRC, 1996) and ASM's Microbiology Curriculum Guidelines (1999) strongly support the use of constructivist-based strategies. The findings in this study indicate that when teachers facilitate learning environments that allow students to explore and construct meanings deeper learning takes place. The problems revealed in this study though are the lack of agreement between the scientific community and the educational community over what types of resources can best fulfill the standards. The data that was collected and analyzed provided strong evidence that human constructivism, the blending of theory and practice can enhance understanding and motivate learners. The problems that impede this blending are the time commitment that teachers must make and the skills they must have in order to accomplish this goal.

## **CONCLUSIONS**

This research study set out to estimate the relative contributions to learning of three instructional strategies. Selected theories of cognitive science and the educational theory of human constructivism formed the theoretical framework upon which these instructional strategies were designed and implemented. The National Science Education Standards set the boundaries that defined the learning environment within which these strategies operated. From beginning to end it was hoped that this study's findings would contribute to understandings of how students learn science. This would benefit science education reform and its goal of science literacy for all Americans.

Students and their interactions with biofilm researchers and with their teachers, peers, and middle school students provided a window through which meaning making in the science domain was observed. Observing, recording, and analyzing how these students learned under the best conditions yielded a large amount of data. Patterns and themes emerged from detailed descriptions of the data. The instructional strategies joined educational theory with classroom practice in a setting contrived by the teachers to facilitate learning.

### **Major Findings**

The focus of the study was on how these biofilm-focused instructional strategies contributed to the female high school biology students' (a) understanding of selected microbiology concepts and principles, and (b) their motivation to study science. The major findings were

- 1) the cutting edge science of biofilms can engage students and students can successfully adapt biofilm images in ways that increase understanding,

- 2) that the ASM CD-ROM did not effectively enhance learning but insights revealed what could make the CD-ROM more successful,
- 3) failed communication with biofilm researchers can be used to learn how to communicate successfully,
- 4) students can successfully adapt an instructional video for cross age teaching,
- 5) and cross age teachers can successfully communicate science and through their teaching, develop understanding, metacognitive skills, self confidence, and increase or maintain their motivation to study science.

Interpretation of data gathered from classroom observations, journal writings, biofilm image products, CAT interviews, the focus group interview, and concept maps revealed many forms of student engagement throughout the ecology unit that was focused on biofilms. The novel adaptations of biofilm images into instructional products that many groups made suggest that cutting edge science can help students can stretch beyond a nominal, or definitional, understanding of a concept.

The pilot study showed that students were unsuccessful at using the ASM CD-ROM to learn about biofilms and microbiology. The CD-ROM seemed to fall short of ASM's goal of increasing microbial literacy. This research study proposes that random distribution of the CD-ROM was ineffective and that teachers may need instructions and/or education in how to integrate the biofilm images into their curricula. The failure to ask teachers to evaluate their instructional use of the CD-ROM made it impossible to determine whether ASM's financial, and other, resources were maximized.

In most instances student attempts at communication with biofilm researchers failed. Evidence was compiled from the E-mail communications, teacher-researcher

communications with ASM and the Center for Biofilm Engineering, journal writings, student debriefings, and CAT and focus group interviews. It is speculated that some of these failures may have been the result of a lack of epistemic fluency between the students and the researchers. The students may not have structured their requests for information in a form that the scientists understood. Often the scientists returned information that was too advanced for the students to understand. More time appeared to be needed for the students to send their requests and receive information than was allowed. The students needed more instruction in how to structure their E-mails and teachers need professional development in how to use this type of communication effectively.

The students were able to successfully evaluate the instructional video as evidenced in their journal writings, student debriefings, and CAT and focus group interviews. Observations of the CAT students by the teacher-researcher and the middle school teachers indicated that CAT students successfully adapted the video in their teaching. Indications were that all of the students did not react to the video in the same way and that there is no one way for teachers to successfully use an instructional video. The teachers effectively used the video to introduce the novel concept of cutting edge biofilm research; a topic that the students knew nothing about. Even though all but the 18 CAT students viewed the video only once the students showed understanding of the concepts. Their references to it when explaining concepts, use of examples in the video, and ability to evaluate its effectiveness reflect their understanding. This suggests that when teachers judiciously plan the integration of an instructional video into the curriculum or a lesson its instructional potential can be maximized.



In general, CAT students successfully communicated science with the middle school students. Teacher-researcher and middle school teacher observations of the actual teaching revealed that most of the CAT students were able to explain the concept of biofilms and provide examples that were relevant to middle school students. There were suggestions that in some cases however, the CAT students could have expanded on the concepts and offered more examples. CAT and focus group interviews indicated that the CAT students were self confident and enjoyed the experience. They often described, in a metacognitive sense, their teaching strategies.

### **Implications of this Study**

#### **Classroom Applications**

Science teachers can use cutting edge science concepts to facilitate student understanding. The lack of student texts and curricula that address these topics should not be a stumbling block for the teacher. Teachers can use the National Science Education Standards, professional organizations such as ASM, their peers, experts in the field and real time computer databases and images as resources during this time of rapid scientific progress in the modern world. Teachers can combine their knowledge of educational and cognitive theory with pedagogy to create learning environments that support meaningful learning. They may meet resistance from their peers as happened with the teacher who dropped out of the study but others like Teacher 2 and the middle school teachers will be supportive of science reform efforts and innovations in instructional strategies. Changes will occur, albeit slowly, that will benefit science education and most importantly, the students.

Knowing in advance that the students may be more interested in relevant science can help the teacher choose how to present the concepts. For example, medical/dental biofilms made science relevant to the students' lives more than any other category of biofilms possibly because students are more familiar with them. Over and over again the topic of dental plaque engaged the students while industrial biofilms, which the students' perceived as being irrelevant, did not. However, those groups that did not get their first choice of topics and investigated more novel topics such as bioluminescent biofilms were also successful. Teachers can encourage students to investigate beyond the familiar and increase their understanding and appreciation of topics that initially perceive as uninteresting.

Students were presented science and technology problems both from the standpoint of ways to destroy biofilms and ways to harness biofilms for the benefit of mankind they wrote and spoke about the negative aspects of biofilms more. This may have been because the students had more prior knowledge of the disease causing aspects of microbes. This is a reminder to teachers not to minimize the effects of prior knowledge and experiences on learning. The concept of biofilms was new to the students and they incorrectly thought a biofilm was a movie about biology. The topic was innovative and the teachers' approach to learning about them was innovative. Many students reported in their journals that they were excited by the prospect of learning about something new.

Signs that meaningful learning took place were evident. Using biofilm images, computer technology, communication with biofilm researchers, and an instructional video - all items in Bruner's (1996) cultural "toolkit" - the biology students became

meaning makers and also began to "think about thinking." Over and over they remarked that they were visual learners and learned best this way. The CAT students even looked at their middle school students in a metacognitive sense when they recognized that they were visual learners too. And when the biology students explained biofilms to the middle school students they thought they learned better because of the experience. They were given the freedom to explore and experience that Langer (1997) advocates for mindful learning.

Using the instructional video to introduce the topic rather than providing a teacher definition of biofilms seemed to work for most of the students. Their interest in the project was captured by the instructional video and they reported in their journals that even though they learned a lot from the video there was much more to learn. Instructional videos can be adapted in ways that enhance learning by bringing students to places where they ordinarily cannot go and enable them to meet real scientists. When a teacher selects a video to use, she must evaluate the relevancy of its content and the effectiveness of its presentation.

Asking the students to adapt biofilm images into an instructional product was a positive factor. Most students reported in their journal writings, the interviews, and the debriefing that they liked working on projects more than listening to lectures. Many of the groups demonstrated that when visual and verbal learning are combined more effective learning takes place (Paivio, 1986). Some were able to creatively transfer mental images into more abstract concepts. The mouse intestine with *Giardia*, the contact lens with *Acanthomeba*, and the *Listeria* growing in a refrigerator represented 3D image products that stretched the imagination.

Those students who showed signs of more meaningful learning adapted the biofilm images in more abstract and creative ways and went beyond the teacher's instructions to create visual representations that contributed to their own and their peers' understanding. They explored beyond the ASM web page and accessed information from other sites. These students were able to explain their products in interesting and easy to understand ways and were able to accurately answer questions about their biofilms.

Those who communicated successfully with biofilm researchers benefited from the experience and referred to what they had learned from them. They also expressed that the project was a positive experience. This research study indicates that communications with science researchers can enhance learning if the teacher manages the process and provides structure. Students have much to gain from these primary resources.

And finally, those CAT students who also taught the middle school students were able to effectively explain biofilm concepts as indicated in the observations and records. They showed a high degree of self-confidence during the presentations and many of them asked if they could teach again the following year. Some of the CAT students changed their peer presentations and adapted them for the middle school students. They related more to the instructional video than the NCAT students because they viewed it twice, which may have had some positive effect. They also showed more metacognitive skills as they reflected on their and their middle school students' learning more than the NCAT students did. The heterogeneous grouping seemed to contribute to the cross age teaching. Several lower ability students were in the CAT

groups and were actually better at speaking to the middle school students. One student in particular originated the idea of looking at dental biofilms under the microscope. Given the freedom to explore and lead she was more successful at learning during this unit than on any other during the year.

Using cross age teaching as an instructional strategy may be difficult for many science teachers. The logistics of having high school students teach middle school students would have to be overcome and time would be needed to train the students. However, this study indicates that cross age teaching should be investigated further.

### **Drawbacks**

The students did not benefit equally from the instructional strategies and these factors have to be considered by the teacher. The students who seem to learn the least were those who were only minimally engaged in learning and did not take complete ownership of the project. A few of these complained in their journals from the first day until the last indicating that even the best instructional strategies and teacher planning could not completely win them over. Group conflicts also had a negative effect on learning though these were rare.

The effortful construction of meaning occurs when students are motivated and it may not be easy to motivate students. Even though several CAT students self-reported no perceived changes in motivation, signs of motivation were there. Rewards such as grades were not reported as being a major motivating factor and only one student said that her reason for wanting to teach was to receive extra points in biology. Most wanted to teach because they thought it would be "fun" and they could "share" what they knew. They were motivated to do well because all of them said they were at least a little

"nervous" and did not want to "mess up." As Mintzes, et al (1997) have shown motivation helps meaningful learning take place because people like to do things which they can understand and at which they are successful. This study showed that the students who enjoyed learning about biofilms and participating in the activities had a better understanding and seemed to be the better teachers. Those students who wrote in their journals that they did not like the project were not as successful. One problem as reported by Tobias (1994) is that it is difficult to estimate changes in motivation. Motivation may not have been high enough after such a narrow intervention to make students want to become scientists or teachers. Though Leslie was one who even thought about teaching science as a career, she was an exception.

The activities could be modified to benefit the lower performers more. These students might also benefit from a written video viewing guide to direct their thoughts during the instructional video. Even though students wrote brief progress reports each day, the teachers might need to monitor the groups more closely. The insignificant results on the written test indicate that assessment of the effects on learning of these instructional strategies should continue to be ongoing, authentic and multifaceted in order to more successfully detect changes in learning.

### **Relationship of Findings to Gowin's Vee**

In the context of this study, science learning under the best conditions, evidence was hypothesized to support the value and knowledge claims proposed in the Gowin's Vee. The value claim that through biofilm-focused learning female high school biology students can become more motivated, self-confident, independent learners, and develop responsibility for their own learning was also supported during the learning activities,

even in those with less academic potential. The degree at which each of these affective traits was expressed fluctuated according to the type of teaching strategy used.

Knowledge claims that were supported by the research included 1) Students became engaged in cutting edge, real world science, 2) Students developed their ability to communicate science and effectively adapted an instructional video and the ASM biofilm imagebase as instructional tools, and 3) Students increased their understanding of microbiology and developed higher-order cognitive skills as evidenced by their ability to visualize abstract concepts

### **Limitations of This Study**

This study was exploratory in nature and even though it examined several sources of data it is limited by the fact that it was conducted under best conditions and therefore, not generalizable to larger populations. Because the study involved only females gender differences were not realized. The difficulty in measuring the effects of such narrow intervention on motivation and understanding and the inadequacies of the written test were other limitations. Additional factors that affected the study were the confounding variables of individual teacher differences and the difficulty of communicating with biofilm researchers. The lack of quality teacher resources on cutting edge science, combined with a lack of time and teacher professional development, make it difficult for overworked teachers to effectively use these instructional strategies. Another limitation is that it is hard to coordinate cross-age teaching because the students are in different facilities. If the teacher who dropped out of the study is any indication, science teachers need encouragement and support if they

are to effectively implement changes in science education. On the other hand, teachers must be held accountable for improving learning environments.

This research study could be improved upon by increasing the size of the CAT group so that a more representative statistical analysis could be completed. A more experimental approach might include a control group that would be taught without using the three instructional strategies. The teacher might lecture a control group of students about biofilms and have them respond to the same pre- and posttest as the group exposed to the three instructional strategies. Various combinations of the three strategies could also be investigated.

### **Further Studies**

This exploratory study revealed some of the benefits and barriers to introducing cutting edge science and selected microbiology concepts related to biofilms in the high school biology classroom. The findings of these female high school biology students tested under the best conditions may (but likely, may not even) be generalizable to highly similar populations and contexts. That is not the purpose of an exploratory study. It is designed to describe, uncover, or at least suggest patterns of successful microbiology learning and increased motivation to study science, under optimal conditions with the intent that promising findings might then be investigated with rigor in large-scale quantitative studies involving a wider range of students.

Future science education research should investigate more thoroughly the short-term and long-term benefits of the three instructional strategies in particular the benefits of cross-age teaching and communication with science researchers both of which resources seem to be underutilized. Two drawbacks to cross age teaching may be the



logistics of setting up teaching situations for high school students and middle school students and knowing how to prepare the high school students. These factors need to be studied. The barriers to introducing cutting edge science and selected microbiology concepts that surfaced in this research should be analyzed more closely to uncover ways to remove these barriers. Specifically, the lack of lesson plans and curriculum guides that teachers can adapt may prevent teachers from using cutting edge science. Teachers often lack the time to research and develop their own activities. Presentations at professional meetings and published research articles can contribute to teacher education about biofilms and other cutting edge science research.

Issues of gender equity in science education continue to need investigation and analysis. Connecting the science domain to the domain of female high school biology students through the use of relevant cutting edge science was shown under the best conditions to increase student understanding and motivation. The impact of these types of strategies on girls' career choices and decisions to study science needs to be investigated further. A long range study of pre-college aged females who are continually exposed to cutting edge science and communication with researchers may yield important information. And more culturally diverse populations should be studied because these strategies may prove to benefit them.

The study indicates that the use of computer technology to adapt images should be investigated further so that their impact on understanding can be determined. The use of instructional videos in classrooms should also be examined in more depth. This study indicates that teachers cannot assume that showing a video one way is effective for all students.

Future studies need to examine the role of the scientific community in improving K – 12 science education. The potential of E-mail communications between students and scientists should be investigated starting with what was learned in this study. Ways to improve the educational quality of resources that the scientific community provides educators could be discovered through more thorough analysis.

This could also contribute to positive advances in science education reform and help provide quality science learning for all. It is only through active approaches such as these that the goal of a more science literate citizenry can be achieved. Learning about microbes can help reach this goal. Microbes can be used to study many aspects of biology because as Lewis Thomas reflected on microbes in The Lives of a Cell,

“The bacteria are beginning to have the aspect of social animals; they should provide nice models for the study of interactions between forms of life at all levels. They live by collaboration, accommodation, exchange, and barter.”

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## APPENDIX A

### GOWIN'S VEE DIAGRAM OF RESEARCH

#### World View:

- ♦ AAAS (1993). There is an urgent need for science education reform.
- ♦ ASM (1998). The National Science Education Standards provide guidance in promoting science literacy for all students in grades K-12.
- ♦ Mintzes, Wandersee, & Novak (1998). Learning can be more effective if educational strategies are improved. These strategies should be based on constructivism.
- ♦ Vygotsky (1934). Students construct meanings through social interaction.
- ♦ Brown (1994). Teachers can facilitate a community of learners in which students are actively engaged in their own learning and that extends learning outside the classroom.
- ♦ Kahle (1992). The learning environment is a major factor in the educational underachievement of girls.

#### Theories:

- ♦ Ausubel (1978). Meaningful learning theory.
- ♦ Paivio (1983). Dual coding theory.
- ♦ Novak (1997). Human constructivism.

#### Research Question

How do biofilm-focused instructional strategies used with female high school biology students and middle school students contribute to patterns in the high school students' (a) understanding of selected microbiology concepts and principles, and (b) their motivation to study science?

#### Sub Questions

Does the cutting-edge science of biofilm research and interactive communication with biofilm researchers help engage these female high school biology students in learning microbiology?

How do these high school students' instructional adaptations of an instructional video on biofilms for middle school reflect their own progress in meaningful microbiological learning?

How do these cross-age teachers (female high school biology students) use an American Society for Microbiology (ASM) biofilm imagebase as an instructional tool to accomplish their goals?

#### Value Claims:

- ♦ Through biofilm-focused learning female biology students will become more motivated, self-confident, independent science learners and develop responsibility for their own learning.

#### Knowledge Claims:

Through biofilm-focused learning:

- ♦ Students will become engaged in cutting-edge, real world science.
- ♦ Students will increase their understanding of microbiology.
- ♦ Students will develop their ability to communicate science.
- ♦ Students will effectively adapt an instructional video and the ASM biofilm imagebase as instructional tools.
- ♦ Students will develop higher-order cognitive skills and visualize abstract concepts.

#### Transformations:

- ♦ ANOVA statistical comparison of pre-posttest on microbiology concepts.
- ♦ Chi-Square statistical comparison of pre- post evaluation of student motivation.
- ♦ QSR NUD\*IST<sup>TM</sup> content analysis of qualitative data.

- ◆ Mintzes, Wandersee, & Novak (1997). Teaching methods based on cognitive science can enhance student learning.
- ◆ Vygotsky (1934). Students construct knowledge through their lived experiences with objects and/or events.
- ◆ Ausubel (1978). Meaningful learning occurs when students relate new information to prior knowledge.
- ◆ Paivio (1983). Students have better recall of information that is encoded in both their verbal and imagery memory systems.
- ◆ Johnson & Johnson (1996). Learning is enhanced when students are engaged, are motivated, take responsibility for their own learning, collaborate with others to reach a common goal, and are allowed to explore.
- ◆ Jonassen (1997). Educational technology can be used as cognitive tools.
- ◆ Brown (1994). Communication with others develops a deeper understanding as students interpret, offer explanations, problem solve, apply concepts, make inferences and present multiple solutions.
- ◆ National Science Education Standards (1996). Learning is enhanced when students examine cutting-edge or real world science that is relevant to them.

#### **Objects/Events:**

- ◆ Participating teachers are instructed in the components of the ecology unit.
- ◆ Students respond to a pre-test on microbiology concepts and the PLAN career interest inventory before learning activities.
- ◆ Teachers use the instructional video to introduce the unit.
- ◆ Teachers facilitate learning while students collaborate with other students and the teacher in learning and peer teaching.
- ◆ Students interactively communicate with biofilm researchers
- ◆ Students use the ASM biofilm imagebase as an instructional tool.
- ◆ Students orally, verbally, and pictorially, reflect on their experiences.
- ◆ Cross-age teachers are instructed in human constructivism and procedures to be used in teaching middle school students.
- ◆ Cross-age teachers adapt the instructional video for biofilm-focused teaching of middle school students.
- ◆ Teacher-researcher and trained student observers take field notes and videotape peer teaching.
- ◆ Students evaluate the learning activities through written responses.
- ◆ Teacher-researcher conducts clinical interviews with selected students and teachers. Students respond to

delayed posttest and PLAN test.

- ◆ Field notes of researching, writing, filming, and editing the instructional video.
- ◆ Content analysis of transcripts of communications between researcher and ASM and Center for Biofilm Engineering.
- ◆ Content analysis of selected videotaped cooperative group interactions and presentations.
- ◆ Analysis of student products that incorporate images from the ASM imagebase.
- ◆ Content analysis of journal reflections of selected high school students.
- ◆ Content analysis of representative communications between students and biofilm researchers.
- ◆ Content analysis of selected videotaped cross-age teaching of middle school students
- ◆ Content analysis of transcripts of selected videotaped student and teacher interviews.
- ◆ Content analysis of selected student-constructed concept maps.
- ◆ Content analysis of student written responses to a project evaluation form.
- ◆ Content analysis of videotaped focus group discussion.

**Concepts:**

- ◆ human constructivism
- ◆ meaningful learning
- ◆ CD-ROM imagebase
- ◆ instructional video
- ◆ computer-mediated communication
- ◆ motivation
- ◆ peer teaching
- ◆ concept mapping
- ◆ microbiology
- ◆ bacteria
- ◆ microorganisms
- ◆ biofilms
- ◆ environmental biofilms
- ◆ medical biofilms
- ◆ industrial biofilms
- ◆ nutrition
- ◆ polysaccharide
- ◆ implant
- ◆ bioprospecting
- ◆ adaptation
- ◆ interdependence
- ◆ pathogen
- ◆ bioremediation
- ◆ food chain/food web
- ◆ classification
- ◆ ecology

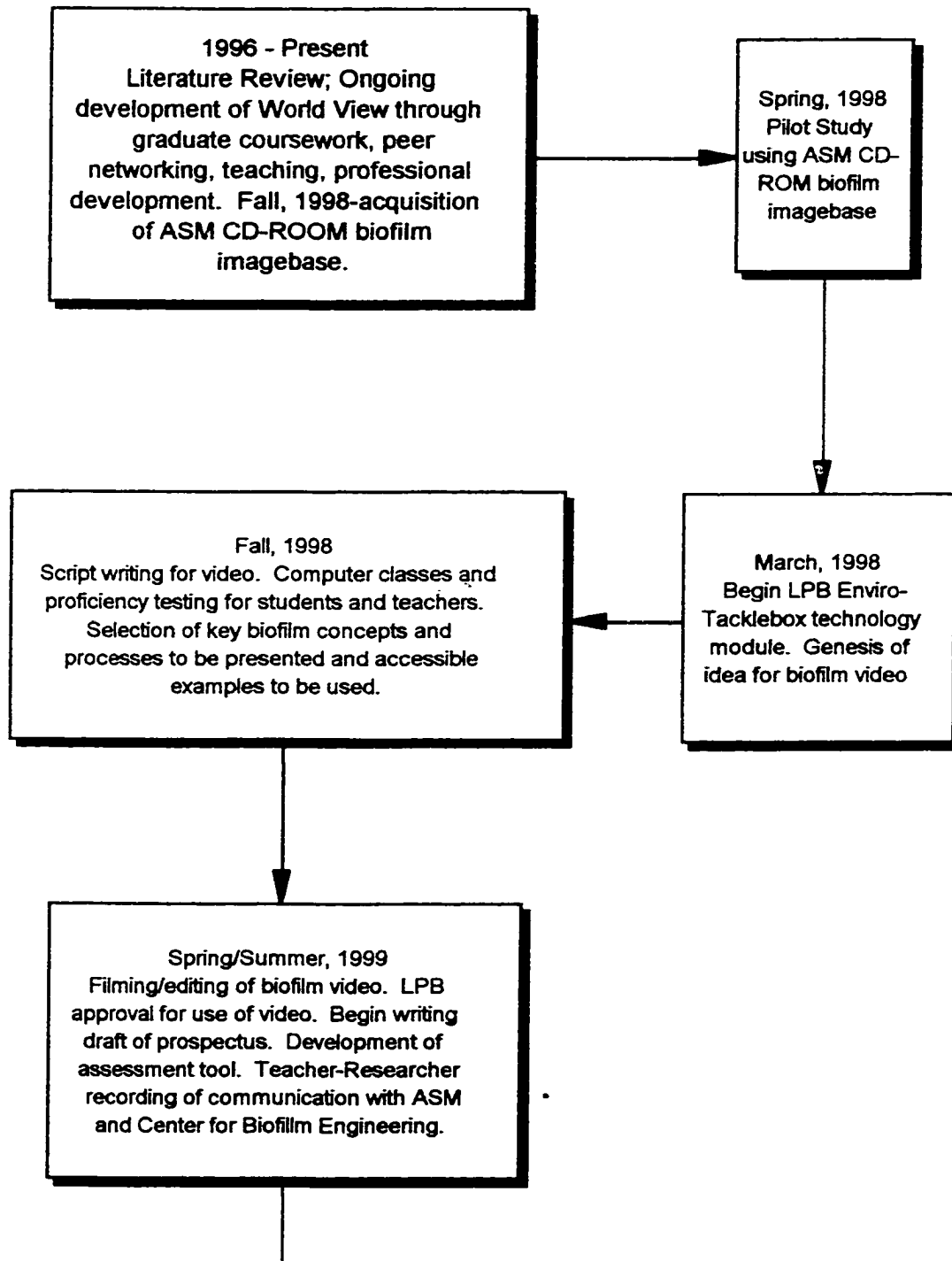
- ◆ Teacher-researcher facilitates focus group discussion.

**Records:**

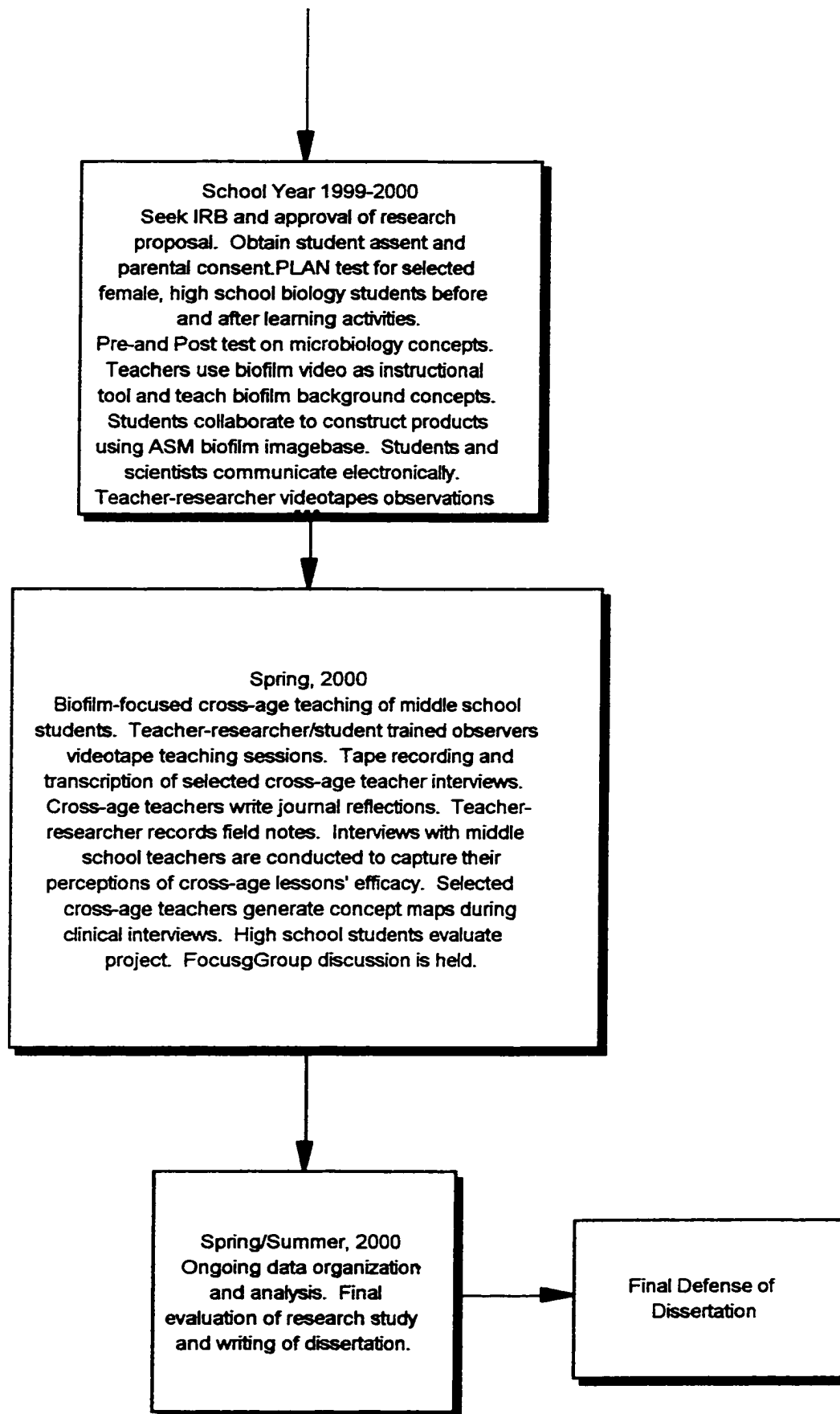
- ◆ Student responses on microbiology pre-post tests.
- ◆ Student responses on PLAN career indicator.
- ◆ Videotapes of selected student cooperative group interactions and presentations.
- ◆ Selected student products that use the ASM biofilm imagebase.
- ◆ Selected written student reflections.
- ◆ Teacher-researcher and student-observer field notes.
- ◆ Records of communications with ASM and biofilm researchers.
- ◆ Records of representative communications between students and biofilm researchers
- ◆ Videotapes of selected cross-age teaching.
- ◆ Videotapes of selected student and teacher interviews.
- ◆ Selected co-constructed concept maps.
- ◆ Videotaped focus group discussion.
- ◆ Student written responses on project evaluation form.

## APPENDIX: B

### FLOW DIAGRAM OF RESEARCH STUDY







## APPENDIX C

### HIGH SCHOOL AND MIDDLE SCHOOL TEACHER PROFILES

| Teacher | Gender | Highest Degree | Specialization     | Experience (yrs) | Current Teaching Assignment                        | Instruction in Standards | Computer Expertise | Instructional Methods Preferences                            |
|---------|--------|----------------|--------------------|------------------|--|--------------------------|--------------------|--|
| HS2     | F      | BS             | Biology            | 15               | Phys Sci Bio                                       | Yes                      | Adv                | Combination of Inquiry, Groups                               |
| HS3     | F      | MNS            | Bio/ Chem/ Env.Sc. | 20               | AP Bio Bio ChemII                                  | Yes                      | Adv                | Combination of Inquiry, Groups, Lecture, Product Based       |
| MS1     | F      | BS             | Elem 1 - 8         | 7                | 6 <sup>th</sup> -grade science                     | No                       | Inter              | Combination of groups, lecture, reading, investigations      |
| MS2     | F      | BA +20         | HS Sci & SS        | 20               | 7 <sup>th</sup> - & 8 <sup>th</sup> -grade science | Yes                      | Inter              | Combination of groups, projects, investigations, questioning |
| MS3     | F      | —              | —                  | 8                | 6 <sup>th</sup> -grade science                     | ?                        | Inter              | Combination of methods                                       |

## **APPENDIX D**

### **BIOLOGY TEACHER INSTRUCTIONS**

#### **WEEK ONE:**

1. Give participating students the pretest on microbiology concepts. Allow 10 - 15 minutes.
2. Explain the Biofilm Project to the students.
  - a) Students will work in cooperative groups of 4 (see Slavin's criteria) using two laptops.
  - b) Students will be in 6<sup>th</sup> and 8<sup>th</sup> hour will be videotaped daily.
  - c) Students will record their work daily in a section in their binder labeled **BIOFILM PROJECT**
  - d) Students will reflect through journal writings during the last 5 minutes of each class period. They will set aside a separate section in the binder for the **BIOFILM JOURNAL**.
  - e) Students will develop the criteria and rubrics for the biofilm image project with the teacher
  - f) Students will be given permission slips to be signed allowing the use of their projects and other records. Anonymity and confidentiality will be maintained.
  - g) Six students from two teachers will be interviewed at the conclusion of the unit.
  - h) Six students from each teacher will go to a middle school class and teach the students about biofilms using the instructional video and their image project.
3. Assign students to groups using a letter and numbering system. Teacher 1 D. Teacher 2, L., Teacher 3, J. Use teacher number, then class period, then Group letter, then member number within the group. Example 1/1/A/1 is D., first period, group A, student 1.  
  
Group Member Responsibilities: 1) recorder (keeps records) 2) facilitator (coordinates, keeps group on task, watches time) 3) mentor contact (communicates with mentor for the group) 4) supply manager (makes sure all materials are at school when needed, cleans up area)
4. Introduction of the project
  - a) Show A Biofilm's Bio video while having students interact through discussion.
  - b) Use the background information from the Enviro\*Tacklebox module to assist in your introduction.
5. Students begin to grow their own biofilm (see video). Check biofilm growth in a week. This can be done later if there is not enough time.
6. Students access ASM Biofilm Project on-line and explore. <http://www.asmtusa.org>  
After you get to this site:

- 1) go to the top of the page and click EDUCATION
- 2) then scroll down & click TEACHERS/SCHOOLS
- 3) then click ASM BIOFILM IMAGE
- 4) go to the collection & look at biofilms
- 5) Make a list of biofilms

Possible discussion questions. What do people need to know about biofilms? How can we teach others about biofilms?

7. Students and teacher develop criteria for the project but these should include:

Information about biofilms, particularly as related to ecology:

1. types
2. location
3. effects of (helpful/harmful?)
4. interactions within the biofilm and with the environment
5. interdependence among organisms
6. species, populations, communities, ecosystems
7. food chain/food web
8. classification
9. how they grow
10. the most interesting fact about this biofilm

Visual representations

1. should be to scale
  2. What best represents this biofilm?
  3. How was the image taken? What technology was used?
  4. Who donated the image?
  5. Why did the group select this image?
8. Groups select image(s) they want to use in their projects. Each group will choose a specific biofilm image(s) to incorporate into a teaching tool that will be evaluated.

### WEEKS 2 - 3

1. Students work on projects in class. During this time they contact a scientist mentor online for assistance. Students should identify themselves and explain the project goals. They should ask a limited number of specific questions about their biofilm and about the scientist's research interests. Copies of correspondence should be kept and turned in later. Students should also keep records of E-mail attempts that were not responded to by a scientist. A thank you E-mail should also be sent to the scientist.
2. Group presentations (10 minutes each). Separate instructions will be given to the cross-age teachers.

3. One month after the presentations and cross-age teaching, students will take the posttest on microbiology concepts and principles. Students and teachers will complete a project evaluation form.

**Suggested Viewing Instructions For  
A BIOFILM'S BIO**

Students are instructed to record their observations during the presentation of the video. Suggested discussion questions are shown in sequence with the video.

PAUSE at Biofilm. What do you think one is?

PAUSE at polysaccharide. Tie this to prior learning.

PAUSE when Biofilm is defined. Discuss term. Where do you think they are found?

PAUSE after visual showing what they need. How does this relate to the needs of other living things? Is a biofilm living?

PAUSE after Wendy helps Greg identify the biofilm. How did Wendy help Greg find out what was growing in his cottage cheese? Tell them to watch carefully as Greg visits the Center for Biofilm Engineering at Montana State University.

PAUSE after Dave talks about technologies used to study biofilms. Discuss what the students know about these technologies.

PAUSE after Body Biofilms. Find out what the students think about this. Can they think of any other places where biofilms might be?

PAUSE after pipes and biocorrosion. What kinds of problems could biofilms cause when they corrode pipes? Ask them if they think biofilms are all bad?

PAUSE after water treatment and mining uses of biofilms. Discuss helpful/harmful biofilms.

PAUSE at the end of medical biofilms. Do the students think these biofilms are a major or minor problem?

PAUSE after the crew arrives at the Norris Geyser Basin. Can anything grow at the extreme (emphasize this word) temperatures of the hot springs and geysers? Has anyone been to Yellowstone?

PAUSE after Dave says "complex community/ecosystem". Discuss what this might be.

PAUSE after Dave talks about how biofilms communicate. Why would they need to communicate? List ideas on board.

**PAUSE** after Dave uses the word "enzyme" and tie in prior knowledge about them.

**Write the term microbial diversity on the board after it is mentioned in the video.**

**Discuss what this might mean later.**

**PAUSE** after "grow your own biofilm" and prepare students for "biofilms found in your personal environment"

**PAUSE** after R. Portier uses the term "decomposer". What does that mean?

**After the video have students brainstorm ways that biofilms are used to help us, ways we remove biofilms, and ways biofilms harm us.**

## COLLABORATIVE GROUPS

Participating students are to be assigned to groups according to the criteria used by Slavin (1990). There will be four students per group. In classes with an odd number of students, one group will have three members.

Slavin's Criteria:

1. Ensure group members are heterogeneous. Use prior achievement as a means of groups being made up of high, medium, and low achievers.
2. Ensure the task requires individual accountability, where each group member has an assigned task or role.
3. Ensure there is a group goal. In assessment tasks, the successful completion of an investigation is an example of a group goal.
4. Make group constitutions flexible. Students want to work with friends, so explain that group make-up will change from task to task.
5. Teach students *how* to work in groups, and make certain expectations are clear.
6. Establish clear criteria for success. In some cases, small groups can complete an investigation while each group member turns in their own report. Or, in some cases, one report can represent the group's work.

## BIOFILM BACKGROUND FOR TEACHERS

A biofilm is a layer consisting of various combinations of many different organisms, frequently, bacteria. The common factor among them is that they grow together in an aqueous (water) environment attached (adhered) to a solid surface, or substrate, forming a film. Together the members of the biofilm form a diverse **community** of individual organisms of different **species**. Biofilms can form on almost any surface that is submerged in nonsterile water. The organisms in the community cooperate and interact with each other and the environment to form an **ecosystem**.

Studying biofilms takes students to the cutting edge of microbiology research where there remains much to be discovered. Most students are interested in learning about something new that relates to the real world. Microbiologists have traditionally, since the time of Louis Pasteur, studied microorganisms in the research laboratory under controlled conditions. They isolate the bacteria and grow them in **pure culture**. A pure culture contains only one species of bacteria. In the natural world, microorganisms often grow as biofilms where more than one species is mixed together in a film. Today researchers view bacteria from a new perspective and have developed different methods to study them in their natural setting. Students can be active participants in the new science of biofilms as it emerges and new discoveries are made.

Biofilm formation evolved as an **adaptation** of its individual community members in their struggle for survival. The microorganisms within the biofilm



produce a sticky glue-like material, or **polysaccharide**, that attaches them to the substrate. This substance makes a biofilm slimy. The attraction of positive and negative charges between molecules on the substrate and molecules in the slime layer attach the microorganisms to the surface. This is somewhat like the attraction of clean hair to a comb on a dry day.

Once attached, the bacteria interacting as a dynamic system try to out-compete other organisms for food. Different types of molecules that bacteria use as nutrients form at the **interface** where the substrate and water meet. The microorganisms within the biofilm can then trap their food more easily than if they were floating around. The nutrient molecules wash by the biofilm. Often a species can cross -feed other species as its waste products serve as nutrients for them. Biofilm formation also serves a protective function for the members of its community. Microorganisms on the inside of the biofilm are often safe from **antibiotics** and **biocides** like chlorine. Protozoans and other predators also have a harder time getting through the slime to the microorganisms. Think of a biofilm as a sort of **microenvironment** or **microhabitat** that gives its living inhabitants a survival advantage.

Some of these microhabitats are in **extreme environments** where most living things cannot survive. The biofilms that are found here have adapted to these extremes partly because there is less **competition** from other species. Many bacterial biofilms have been found growing in the hot springs of Yellowstone National Park where the temperatures may reach 115 ° C (239 ° F) and the water is boiling! In comparison, the upper temperature limits for plants

and animals is less than 50°C (122°F). Biofilms have been found in both acid and alkaline hot springs in Yellowstone. The **pH** of the springs may drop to an acidity of 1.3 or may be as alkaline as 9.

You cannot see the individual bacteria in a hot spring because they are microscopic but you can tell they are there because of the color of some hot springs. These biofilms are **microbial mats** floating on the water's surface. The millions of bacteria in them contain green, red, yellow, or orange pigments that we can see. Some hot springs appear blue as the sunlight is refracted off them. Others are orange or even purple. If we could not see the colors, we would still know bacteria are there because some hot springs smell. Some types of bacteria use sulfur as their energy source and produce hydrogen sulfide as a waste product.

Biofilms are basically everywhere. They can grow on inert surfaces in the environment where their effects are greater than if they were single organisms. During **biofouling** they can corrode pipes or the hull of a ship and contaminate water purification filters. Growing on stainless steel surfaces used for food preparation in the food industry, they can contaminate cheese or meat. Biofilms grow on the porcelain surface of toilet bowls, wood siding, shower tiles, plastics, and wooden cutting boards. Biofilms are everywhere! Scientists would say they are ubiquitous.

Biofilms can also grow on living cells and on surfaces inside organisms. They can potentially grow on anything that is inserted into the body. Biofilms often form when indwelling vascular catheters (IVCs) are placed into a major

vein and left for long periods of time for use in antibiotic therapy and chemotherapy, blood transfusions, and intravenous feedings. There are numerous types of body **implants** and **prosthetic devices** such as contact lenses that provide surfaces for biofilms to grow on. Mascara brushes, eye care solutions, and artificial fingernails may also provide a safe haven for biofilms. Biofilms may grow in the upper respiratory tract, the gastrointestinal tract, or the urinary tract often causing serious illness.

Dental plaque is probably the first biofilm to ever be studied. Anton van Leeuwenhoek, who is credited with the first use of magnification to observe microorganisms, actually looked at scrapings from around his teeth. The mouth can be a home for an estimated 400 different species of bacteria. Teeth provide hard surfaces for biofilms to form on. Our saliva and the remains of food we eat are both sources of nutrients for oral bacteria that can form **dental plaque**. As they feed they produce acids such as lactic acid that may wear away the enamel surface of your tooth. Over time this can cause a cavity that can destroy the tooth. Biofilms also cause **periodontal disease** that affects the gums and other tissues in the mouth.

Not all biofilms are harmful, but some may actually help the organism that they live inside. There are biofilms that are part of the **normal flora** inside our bodies, such as those in our digestive tract. These biofilms are **probiotic** and protect us from infection by pathogenic bacteria. Probiotic bacteria in the urinary tract fight off bacteria that cause urinary infections. Bacteria in our intestinal tract process undigested food particles so that our bodies can remove

them as solid waste. Some types also help us produce vitamins such as vitamin D. Biofilms are also important in the environment. For instance, in aquatic ecosystems, biofilms serve in **food chains** and **food webs** as a food for many other organisms such as protozoans and small invertebrates. Biofilms in the soil help plant roots obtain substances such as nitrogen. Other bacteria help decompose the remains of dead organisms and recycle nutrients.

Throughout history, many types of technology have been developed that are either used to study biofilms, control biofilms, or use them to our advantage. **Technology** represents the products and systems that man has developed in order to meet a human need or solve a problem. **Biotechnology** is a special type of technology that uses organisms to solve problems. It is a growing industry that is proving to be extremely beneficial to mankind. Researchers can use biotechnology to manipulate genes and produce large amounts of products such as antibiotics or hormones that save human lives. Biofilms can be used in biotechnology. Putting certain biofilms on feed that ends up in the digestive tracts of cows can help prevent diseases. Biofilms are also used in **water purification** to convert wastewater such as sewage into fresh water for drinking and other uses. **Biodegradation** uses biofilms to break down toxic wastes such as oil spills or groundwater contaminants. A new research area known as **bioprospecting** harvests biofilms from the environment to use in biotechnology. An enzyme used in the polymerase chain reaction (PCR) was originally harvested from the hot geyser springs at Yellowstone Park. PCR helps scientists amplify tiny amounts of DNA to make more of it so they can study it better.

This is often helpful in solving crimes where only small amounts of DNA are found. Scientists use this enzyme because it can withstand the high temperature used during PCR.

## **APPENDIX E**

### **PILOT STUDY OF ASM CD-ROM USE BY BIOLOGY STUDENTS**

The purpose of the pilot study was to reveal how selected female, high school biology students at a parochial high school for girls in the Deep South responded to the ASM biofilm imagebase CD-ROM, so that in the proposed study of instructional methods student use of the computer and the imagebase would not confound the problem. Purposeful sampling was used in which eight information rich cases in a Biology I Honors class were studied in depth over a three-week period. A brief set of questions was used to evaluate the prior knowledge of microbiology and biofilms that the participating students had. A teacher who taught computer skills to sophomores was interviewed to determine the expected level of expertise these students brought to the process.

Release forms were signed by the participants and their parents in order to ensure privacy and confidentiality. Anonymity of both the students and the school was preserved.

After explaining the purpose of the study, assessing prior knowledge, and introducing the concept of biofilms and the CD-ROM, this teacher-researcher served as a nonparticipant observer. The units of analysis were individual students and cooperative groups of three students.

### **Summary of Procedure**

- 1) Interview of computer skills instructor.
- 2) Explanation of research procedures and confidentiality to students and securing signed permission form.
- 3) Assessment of student prior knowledge of biofilms.
- 4) Teacher presentation of overview of biofilms and the CD-ROM imagebase.
- 5) Assignment of student volunteers to individual processing or group processing.
- 6) Observation of group discussions of members' expectations of what would take place.
- 7) Observation and videotaping of individual and group processing of the imagebase. Recording of field notes and transcriptions of these events.
- 8) Observation of subsequent group discussions of what occurred during processing of the imagebase.
- 9) Audiotaped structured interviews of selected individual and group member informants.
- 10) Videotaped structured focus group interview at the debriefing that followed the processing events.

Participating students were asked to "think aloud" during the time spent on the computer processing the CD-ROM imagebase.

Time was allotted as follows

| <u>CASE</u>           | <u>OBSERVATION 1 (min)</u> | <u>OBSERVATION 2 (min)</u> |
|-----------------------|----------------------------|----------------------------|
| Individual 1          | 30 (process)               | 30 (process)               |
| Individual 2          | 30 (process)               | 30 (process)               |
| Group 1               | 10 (pre-discussion)        | 10 (pre-discussion)        |
|                       | 30 (process)               | 30 (process)               |
|                       | 10 (post-discussion)       | 10 (post-discussion)       |
| Group 2               | 10 (pre-discussion)        | 10 (pre-discussion)        |
|                       | 30 (process)               | 30 (process)               |
|                       | 10 (post-discussion)       | 10 (post-discussion)       |
| Teacher Introduction  | 10 - 15                    |                            |
| Focus Group Interview | 20                         |                            |
|                       | <u>INTERVIEWS (min)</u>    |                            |
| Computer Instructor   | 15 - 20                    |                            |
| Individual Informant  | 15 - 20                    |                            |
| Focus Group           | 15 - 20                    |                            |

Triangulation of the data was accomplished through observation, interview, and artifact analysis. Every effort was made to understand the events as they occurred and be open to design changes as they became necessary. The goal of this research was to develop a rich and informative account of what actually happened.

### Analysis

This multi-case study was an attempt to develop a richer understanding of the research question: How do selected female, high school biology students process the ASM biofilm imagebase? As explained previously, this understanding would enable the teacher-researcher use the imagebase more effectively in a larger dissertation study.

### Observations

The study began with a general descriptive observation, or grand tour, that enabled the teacher-researcher to focus on the general research question: How do selected female, high school biology students process the biofilm imagebase? Mentally, several questions were asked that guided mini-tour observations and allowed



elaboration on the general descriptions of the setting and participant interaction that took place there. Some of these questions included:

- 1) How can all the actors and their acts, activities, events, and goals be described?
- 2) What are all the feelings the students felt and expressed during the observations?
- 3) What was it like to work in a group or to work alone?

Prior to starting the formal field observations, each student was asked to answer three questions individually and as completely as possible. They wrote their answers on paper and gave them to the teacher-researcher when they reported for the processing of the imagebase. The pre-assessment included

- 1) Describe your computer expertise.
- 2) What do you know about microorganisms?
- 3) What do you know about biofilms?

Next, observations were made of two individual student participants and two cooperative groups of three student participants each, processing the ASM CD-ROM biofilm imagebase in two trials without prior instruction. The two trials took place back to back taking a week to complete the observations of each individual case. Following the processing, the eight participants were also observed together discussing their experiences with the imagebase. When each participant arrived for her first trial, a brief explanation was read to her about microorganisms and biofilms, the purpose of the study, and the procedure that would be followed.

Observations took place immediately after school in the computer lab that is described in detail in the analysis. The teacher-researcher observed each participant, or participant group, processing the imagebase for 30 minutes during each trial. The two groups of three students were additionally observed discussing for 10 minutes prior to processing (pre-discussion) and for 10 minutes immediately following processing (post-discussion). The students were asked to think aloud during the processing. They were not asked formal questions because these were later asked in interviews. There were some informal moments when the teacher-researcher and participants talked about what was going on. These included moments spent waiting to get started, before or after biology class, and while some were eating the pizza provided to them on the last day. Field notes were recorded during the observations and were later typed and organized. The field notes were reviewed within a day after each observation.

At the conclusion of the students' trials a focus group discussion of the processing experience by all eight participants was videotaped. This took place in the biology classroom while 16 other students worked quietly at their lab table desks. The participants were grouped in two rows forming a semicircle in the back of the room.

The participants were purposefully selected from the Biology I Honors class based on their availability, performance level, science ability, motivation, grade level, and computer skills. They included two individuals, I1 and I2, and two groups with students A, B, and C, designated as G1A, G1B, and G1C or G2A, G2B, and G2C. I2 was a freshman honor student who was highly motivated, interested in science, and was consistently an "A" student. She had limited experience with computers and had not taken a computer applications course. In her pre-assessment, she wrote that she did not

“know too many things about computers” but “I know how to run certain programs and I learn pretty quickly after I am shown how to do it.” It was a sophomore whose biology performance level was consistently average, frequently missed homework assignments and only completed assignments if she was required to do them. She characterized herself as “computer illiterate” but wrote that she knew “all you want to know about Microsoft Word Perfect, PowerPoint, Excel.” She was also taking the computer applications course. Both individuals reported that their knowledge of microorganisms was limited and they knew they are “small” and that there are many types. Neither was familiar with the term biofilm.

All of the G1 students were sophomores and their grades in biology fluctuated between “A” and “B”, indicating above average performance. They appeared to be interested in science and were motivated to learn. All were currently taking the computer applications course. G1A had taken computer classes since fifth grade and was “comfortable” with computers. All reported being able to use the Internet, PowerPoint, Excel, Microsoft Word, and a CD-ROM. G1B stated that she could also install programs. All three indicated that they knew nothing about biofilms. G1A wrote that microorganisms are “microscopic...very small, non complex, Eukaryotic cells.” She had the misconception that they are eukaryotic. Student G1B thought microorganisms were “very small, microscopic...non-complex organisms similar to eukaryotic cells. They contribute to the making of more complex organisms.” G1C also knew that they are microscopic. She wrote, “I think they may not be able to carry out special functions (like prokaryotes).” “They are everywhere and scientists do not know much about them.”

The G2 students were also sophomores with students G2A and G2C being consistently “B” students in biology and G2B fluctuating between “B” and “C”. G2B was not as assertive in the classroom as the other two and was not as self-assured. All three indicated that they had computers at home and were as experienced as the individuals in G1. G2A said of biofilms, “From the beginning of the word I conclude that they are films about biology.”

G2B had the same impression and G2C knew “nothing” about biofilms. G2A reported erroneously that microorganisms are “small invertebrates”. All three agreed that they were microscopic but G2B added that they were “single-celled.”

The CD-ROM that was used was not prepackaged software, but an imagebase of 55 images of biofilms, examples of how to use the images in PowerPoint presentations, and text material. It was designed to be used by the pre-college or undergraduate science teacher who could tailor it to her/his instruction about microorganisms.

Relevant folders included

- 1) IMAGEAXS. This included the imagebase and contained thumbnail images, full screen images, and text information. The user could access this program to sort and locate images using different criteria.
- 2) READ ME. This folder contained instructions on the use of the imagebase.
- 3) PPOINTEX. This folder contained PowerPoint presentations that could be used as examples.

The high school where students were observed has Microsoft PowerPoint and MicrosoftWord, which could be used with the imagebase to make presentations or print graphics. There were no programs at the school that could be used to produce movies

but the CD-ROM program had instructions on how to integrate the imagebase with such software. Images and text could also be printed and many of them were color images.

Observations of the students participating in the event of processing revealed a wealth of information, only some of which is reported here. The event of processing was observed to consist of several activities. Participants “looked around”, tried to “figure out” what to do with the program, actively learned about biofilms, and interacted socially. Actions observed during “looking around” included moving fairly quickly through several displays such as the Thumbnails View, in which several images could be viewed simultaneously, and the Text List View, where the text data from a collection was displayed. Students also viewed the Info Sheet View that displayed the thumbnail, text information, and keywords for individual images. The Source Image View was a single large image of a certain biofilm. The groups observed the Slideshow that cycled through records in a collection, one image at a time. They also enlarged images, went through Searching and Sorting, and tried to access HELP, which was inoperable. They used the pull down menu most often and only later in the processing became familiar with the toolbar.

“Figuring it out” sometimes meant trying to understand the purpose of the program and other times meant trying to make a project of their own. The students organized images into different categories, rearranged “pictures,” and tried to export images to PowerPoint. One group even succeeded in viewing a movie and “figuring out” how to make one of its own. The rate at which participants moved from icon to icon varied. I1 moved rapidly, almost aimlessly, through the program, clicking on

images and reading only the beginnings of commentaries. I2 moved deliberately and read all of the text under each image, interpreting its meaning aloud. The two groups moved at a rate intermediate to that of the individuals.

Actively learning about biofilms took many forms. Students were observed making connections to prior learning when they compared biofilms to “ecosystems” and talked about their role in “food chains”. Some tried to pronounce scientific terms and sometimes determine their meaning. One student even explained the meaning as she read the text. G1 recognized that the scale bar on the image was to show the size of the microorganisms, but did not remember that a micron is equal to 0.001 millimeters. The students exhibited higher order thinking skills, such as reasoning and making inferences and predictions. G2 searched the images and made a game of comparing images to familiar objects by saying “looks like”. Participants were also able to group images according to similarities and separate them by differences.

The students in the groups were observed to be interacting in several ways. They encouraged each other, took turns moving the mouse, and collaborated on what to do next. Their reactions ranged from being very vocal and calling out together at times to quietly waiting for another to speak first. Sometimes they were even silent throughout.

Goals were set before, during, and after the processing and they changed frequently. Sometimes there were no specific goals. In the pre-discussion before the first trial, goals were centered on learning about biofilms but changed to “figuring out” the program during the processing. By the second trial the goals were to process faster and do a better job. Not meeting goals created numerous feelings throughout the

observations and frustration was a major one that everyone had at one time or another. Excitement, amazement, disgust, boredom, intimidation, and anticipation, are some that were evident at various times. Feelings were openly expressed, both verbally and through body language, while students were participating in the activities.

Structural questions that guided focused observations include the following

- 1) What are all the kinds of text in the imagebase?
- 2) What are all the kinds of group interaction?
- 3) What are all the feelings?
- 4) What are all the kinds of projects?

Four domains were analyzed and these guided the focused observations.

| <b>DOMAIN</b>  | <b>SEMANTIC RELATIONSHIP</b> | <b>COVER TERM</b>   |
|--|------------------------------|---------------------|
| getting in<br>looking around<br>figuring it out<br>viewing a project<br>making a new project | → is a kind of →             | Processing Activity |
| encouragement<br>turn taking<br>collaboration<br>brainstorming<br>leading<br>following       | → is a kind of →             | group interaction   |
| movie (PowerPoint presentation)<br>slide show<br>print<br>multimedia                         | → is a kind of →             | project             |
| frustration<br>excitement<br>boredom<br>disgust<br>intimidation<br>pride<br>anticipation     | → is a kind of →             | feeling             |

Each of the participants was able to access text of different kinds associated with the imagebase. Whether or not they read and/or interpreted the text varied. A text list displayed the author, title, view (magnification), file number, and the subject. The students found the text list but did not use it. The key words view contained terms from the commentary. Students located it and tried unsuccessfully to use it. The info sheet view was used frequently to read about the biofilm represented by the image and its author, subject, and category, such as environmental, industrial, or medical/dental.

Group interactions were complex. The individuals were highly supportive of each other, almost to the point of cheering them on during the processing. They bounced ideas off each other by brainstorming before, during, and after the processing. Their facial expressions often indicated that they were thinking about what the other person was saying. Often, they repeated what one said, in agreement. Encouragement was often verbal and they used expressions such as “go, girl”, “you can do it”, and “yes!” They patted each other on the back and nodded in support. They usually took turns when speaking, but when the excitement was high, they all spoke at once. They also took turns leading the group. The first day a leader emerged in each group and the other two participants followed. By the second day they were sharing the role of leadership. Collaboration was evident when they reached a consensus on what direction to take and what goals to aim for.

The kinds of projects that the CD-ROM had included movie, slide show, print, and multimedia. Movie was the term used, but it actually was a PowerPoint presentation unless the computer had multimedia capabilities. None of the groups was able to produce a multimedia project, or understood that one could be done. However,



G2 suggested that sound could be added to the movie and make it more interesting, hinting at the idea of a multimedia possibility. The individuals did not make a slide show. The groups both observed a slide show example and produced one of their own. They were able to change the timing of the cycle and rearrange images in a slide show. None of the groups discussed printing or attempted to print any images or text. Both groups recognized that PowerPoint could be used to produce a movie, but only G2 was able to watch a movie. They began to export an image when the observation time ended and may have been able to produce a movie if allowed the time to do so. G1 realized that the possibility was there but could not produce or watch a movie.

Feelings were expressed openly as stated before. Frustration was common but only I1 remained frustrated throughout the entire observation. The group members were excited when they found something new as expressed by “wow”, “geeze”, “look at that...” and so on. When the biofilms were more relevant to them they were often disgusted. The tooth image showing dental caries was the one they all exclaimed over. I1 remained intimidated throughout and worried that she would “break the computer”. At the end of the first trial, everyone but I1 anticipated what she would do the next day. G2B at one point said, “this is boring” and looked at her watch. Both groups exhibited pride in their accomplishments but at the same time expressed that they wished that there were more time to finish what they had started.

A taxonomic analysis of the group interaction domain and the text domain was conducted as shown below.

### **Kinds of Group Interactions**

1. encouragement
  - 1.1 verbal
  - 1.2 nonverbal
    - 1.2.1 nod
    - 1.2.2 touch
    - 1.2.3 smile
2. turn taking
  - 2.1 giving instructions
  - 2.2 reading text
  - 2.3 moving the mouse
  - 2.4 talking aloud
3. collaboration
  - 3.1 deciding where to go
  - 3.2 deciding how to get there
  - 3.3 setting goals
  - 3.4 interpreting information
4. brainstorming
  - 4.1 calling out ideas
5. leading
  - 5.1 controlling the mouse
  - 5.2 speaking over others
  - 5.3 speaking first
6. following
  - 6.1 sitting quietly
  - 6.2 looking towards the leader

### **Kinds of Projects**

1. movie (PowerPoint presentation)
  - 1.1 use PowerPoint for text
  - 1.2 sequence images
  - 1.3 export images
  - 1.4 import images
  - 1.5 import graphics
2. slide show
  - 2.1 set timing
  - 2.2 sequence images
  - 2.3 import images
  - 2.4 import graphics
3. print
  - 3.1 info sheet view
  - 3.2 enlarged image
  - 3.3 Source Image View
  - 3.4 graphics

3.5 desk top publishing  
4. Multimedia  
4.1 sound  
4.2 video  
4.3 animation

To focus observations even more, the following contrast questions were asked

- 1) What is the difference between leading and following?
- 2) What is the difference between brainstorming and collaboration?
- 3) What is the difference between encouragement and turn taking?
- 4) What is the difference between a movie (PowerPoint presentation) and a slide show?
- 5) What are the differences between print and multimedia projects?

Students were observed leading when other students deferred to them. When leading, the student would talk more and offer more suggestions. The other group members would follow her suggestions and face her more. Following was different because a student would refrain from talking, or do what the leader said to do. Also, when leading, the student controlled where the group would explore and often initiated the ideas that the group followed. In contrast, following involved little individual decision making. During brainstorming, each student was free to spontaneously verbalize her ideas. Brainstorming did not always involve conscious decision-making and all ideas were accepted as potential actions. Collaboration, on the other hand, occurred when the group analyzed several individual ideas and reached a consensus on how to act or on the meaning of a concept. Encouragement and turn taking differed in several ways. Turn taking meant waiting until someone else completed a task or a thought. Encouragement supported turn taking and was often vocalized while the

individual was working. Encouragement was largely verbal and turn taking was mainly nonverbal.

The kinds of projects available represented different uses of the program. The term movies was used out of context in the program. Computer movies usually have animation but the example on the CD-ROM was actually a PowerPoint presentation with still slides. The CD-ROM movie contrasted with a slide show because it included text and the slide show example did not. The images in a slide show could be rearranged, but the sequence in the movie was necessary to its meaning, and as such could not be changed. Observations of print and multimedia project possibilities were made only from the CD-ROM itself, because none of the students developed projects in these areas. It is noted that multimedia could combine video, animation, and sound, and therefore brought ordinarily two-dimensional material to the third dimension. Print is two dimensional and more limited in its presentation. The pre-assessment indicated that these students did not have skills for using multimedia, but they did have skills for producing projects in print.

The cultural domain, kinds of group interactions, was chosen for componential analysis. The various subsets were entered in the domain section of the paradigm below.

| <b>DOMAIN</b> | <b>DIMENSIONS OF CONTRAST</b> |               |             |                            |            |
|---------------|-------------------------------|---------------|-------------|----------------------------|------------|
|               | Verbal expression             | body language | controlling | Individual decision making | analytical |
| Encouragement | Yes                           | Yes           | no          | Yes                        | no         |
| turn taking   | Yes                           | Yes           | no          | Yes                        | no         |
| Collaboration | Yes                           | Yes           | no          | No                         | yes        |
| Brainstorming | Yes                           | Yes           | no          | Yes                        | no         |
| Leading       | Yes                           | Yes           | yes         | No                         | no         |
| Following     | Yes                           | Yes           | no          | No                         | no         |

Interpretations of the observations made have gradually evolved from the teacher-researcher's presence as a participant observer and content analysis of the field notes, the student pre-assessment papers, the CD-ROM biofilm imagebase, and the videotaped observations. The data collected and recorded was almost overwhelming; however, focused and selective observations guided the teacher-researcher to a more manageable approach. The final observation of the focus group discussion offered more insights and helped the students evaluate their experiences.

Several things stood out during the group interactions. Individuals I1 and I2 did not progress as well as the groups due to their being "stuck" and not having other people with "insights" to talk to. The advantages of group collaboration and support were clear in the students' comments, feelings, and actions. One student said that the other members of her group, "wouldn't give up with you." The individuals moved more slowly through the program, did not accomplish as much, and did not show

evidence of learning as much about biofilms. Number I2, who is a student with a higher ability level, was able to learn by taking her time and making meaning out of the experience, even though her computer skills limited her.

Computer skills appeared to be important in this multi-case study. Familiarity with computers gave all except I2 the confidence to jump in and try anything. The sophomores, who had just completed training in the use of PowerPoint were anxious to produce a project. They frequently referred to what they had learned in computer class.

Even though the computer program had instructions, the students expressed the need for more direction. Though they never used the work “teacher”, they indicated that someone experienced with biofilms and the program was needed to instruct them. In the group discussion, they talked about the need for a “person” to instruct them. An interpretation of this was that learned skills are needed if students are to successfully use computer-assisted technology as cognitive tools in learning. It appeared that without instruction, they spent a large part of their time “looking” and “exploring” the program and not acquiring knowledge about biofilms.

The need for teachers to be more aware of feelings was emphasized by their open expression. Individual I2 was so frustrated and discouraged that she learned little about anything. The more successful the groups were, the more they liked working in the program and the more they learned about biofilms.

### Interviews

Formal interviews of approximately 15 minutes each were conducted with the computer applications teacher as informant and two groups of student informants who it was thought would provide rich information to reveal more about how female high

school biology students process the ASM CD-ROM biofilm imagebase. The teacher was selected because she taught the sophomore level computer applications class and could provide insight as to the participants' computer skills and experience with computers. It would also be desirable to know what instruction methods she used successfully. She was the head of the school computer club and had taught computer applications for three years. Her expertise was represented by the fact that she held a bachelor's degree in business education and was certified in computer literacy. She was well liked by the students and was considered an excellent teacher by students, parents, faculty, and the administration. She had attended several professional conferences, was enrolled in graduate school in a computer-based program and was up to date on computer technology.

The student informants were purposefully chosen because of their variety of computer skills, motivation in science, and ability and performance levels in science. These students provided four different perspectives and added depth to the study. Both individual participants were interviewed together, in order for each to help the other remember more details about their experiences. These individuals were previously described. A third interview was conducted group members G2B and G1B together in order to obtain information from a member of each group and also to assist them in remembering more details. These two students were also described in the observation section of this paper.

I asked the following questions of the computer applications instructor:

Descriptive -

1) Can you describe the computer education programs that

freshmen and sophomores are enrolled in?

- 2) Can you describe a typical class in which students are first instructed in the use of a specific computer activity?

Structural -

- 1) What are the levels of computer competency of a typical sophomore?
- 2) What types of approaches do students make to computer technology that is new to them?

Contrast -

- 1) How do you think the level of a typical student's motivation to use computer technology changes from the time she enters the school through her sophomore year?
- 2) What are the kinds of computer technology used in class rooms in your school?

These questions would yield deep information about the computer skills of the participants and how computer technology was presented to them in formal instruction.

The questions asked of the student informants included:

Descriptive -

- 1) Can you describe in detail the ways you (your group) processed the CD-ROM imagebase?
- 2) Can you describe in detail the experience of working alone (in a group) to process the imagebase?

Structural -



- 1) What are all the feelings that you felt and expressed before, during, and after your experience?
- 2) What types of goals did you (your group) have at the beginning, during, and after your experience with the imagebase?

**Contrast -**

- 1) Compare your knowledge of biofilms before processing the imagebae with your present knowledge.
- 2) Compare what you accomplished using the imagebase with what you think you could do now.

These questions were relevant because they enriched the understanding of processing the imagebase by providing the students' perspectives of it. They revealed more patterns within each case and across the individual cases. What was observed was greatly influenced by the teacher-researcher's presence and perspective. These interviews contributed to the triangulation of data collection and to the validity of the research.

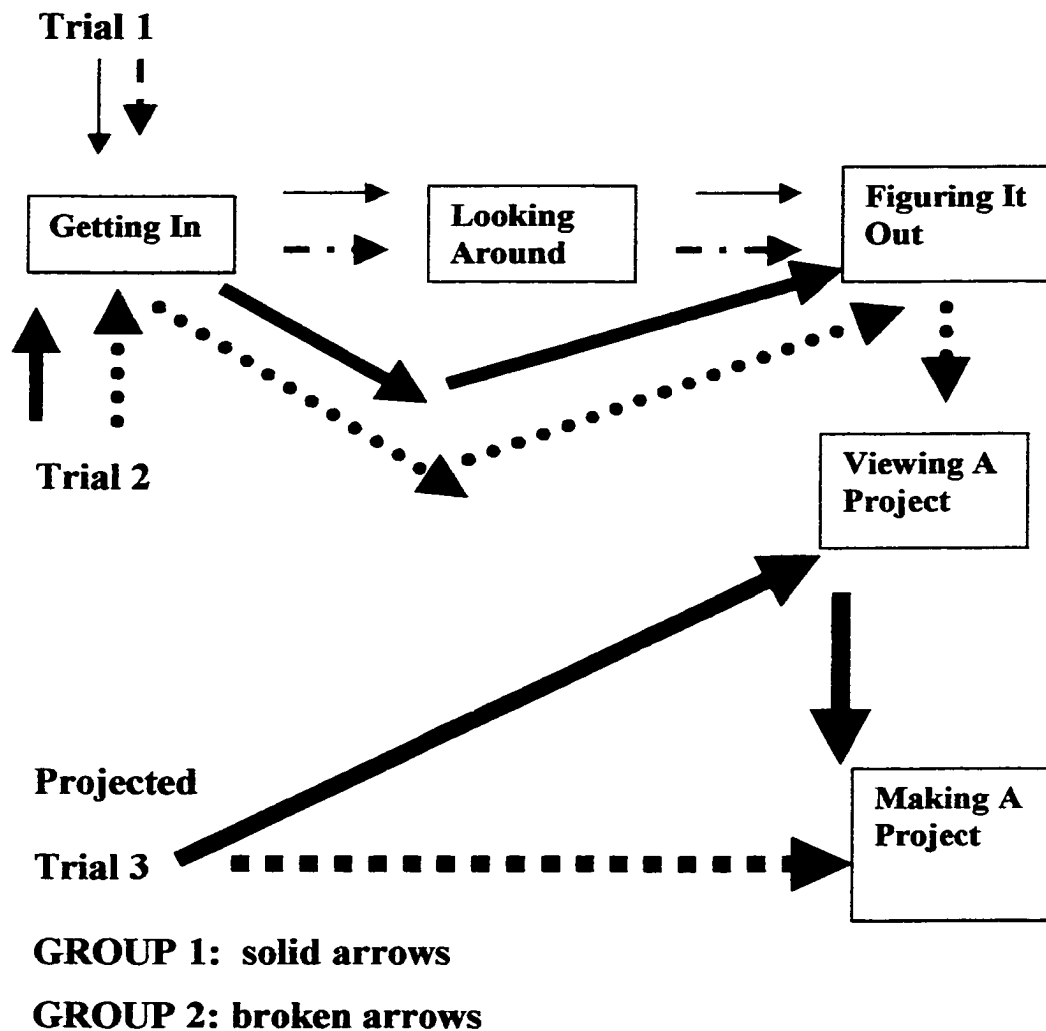
The Computer Applications teacher's responses indicated that the sophomores had experience in Microsoft Word, Excel, and PowerPoint. She indicated that they could "pull sound off the Internet and record it off the CDs" using the computers in the classroom. She also said that the benefits of group work varied according to the individual students. Some students performed better working alone but other students working in the class sometimes helped each other. This teacher's instruction was hands on. She found the students coming into the class each year with more experience and

attributed this to the fact that most of them have computers at home. The students were more “computer literate” that year and not afraid to use the computers as much. They were also using computer-assisted technology more in other classes and were recognizing the value of computer skills.

The group informants revealed how they processed the imagebase. They “looked around” and “pressed all the buttons” on the first day. By the second day they wanted to “figure it out” and do more than just “looking [sic] at the pictures”. Both groups realized that they could do PowerPoint presentations though Group 1 did not even try to do a presentation. The informants said that before the processing they did not have a goal. During processing they developed the goal of trying to “figure it out”. “Now the goal would be to make a presentation.” They thought that lack of time was the only thing holding them back. Group member G2B kept referring to the images as the “same old pictures” suggesting that she was not interested in biofilms. This group learned that biofilms are everywhere and thought that they could explain them to someone else. They liked working in the group and saw that individually it would be much harder. They saw each other as a resource because “we had our own separate ideas.” Group member G2B talked about running into “dead ends” and needing the group to get out of being “stuck”. They thought that having their peers instruct them would be better than having a teacher instruct them. The individuals basically corroborated what the group members said about working together or alone. Individual I1 concentrated on the negatives while I2 saw value in the experience. I1 thought that the best instructor would be a teacher. She also kept referring to her “breaking the computer” thus indicating a lack of self-confidence.

Several different patterns appeared across the separate cases. The group approach to the imagebase was more orderly and sequential than that of the individuals and indicated that collaboration increased understanding and the accessibility of computer technology in a learning context.

### Sequence of Activities for Groups



The large difference in individual approaches could be the result of differences in computer skills, motivation, interest level, level of self-confidence and overall ability.

A pattern that unfolded is that, if the students were at the same level of computer literacy, they approached unfamiliar programs in a similar manner. The projects that the students were most interested in were PowerPoint related and they had just learned how to construct these in computer applications class. This newly acquired knowledge seemed to be more exciting to them and it was surprising that even though the students were very familiar with printing no one printed out any images. This might have been because printing had become an ordinary activity for these students.

Ability level, motivation, and interest seemed to interplay in the active learning about biofilms. Group 2 was more successful than the others at analyzing words, connecting new knowledge to prior knowledge, and making connections. Two of the students in that group were active participants in biology class and asked questions frequently. Their “sounds like” game made it fun for them. All of the students exclaimed with “disgust” over the biofilms that were more relevant, such as the one growing on the teeth and the one on cheese. Group interactions enhanced learning because the groups made more connections to prior knowledge and explored more inferences. They were more active learners and were able to remember more about biofilms after the processing. These patterns across the groups and the lack of them in the individual's experiences was enlightening.

Though I1 did not like talking aloud as she worked, brainstorming out loud in a group seemed to help in the learning process. It might have helped her if she had given it a chance. Her negative attitude appeared to hold back her progress. Group leading and following appeared to be shared, much like turn taking. This indicated mutual respect for each other and appeared to improve the group outcome. The expression of

feelings occurred in patterns also. Frustration was common to all and entered the process almost immediately but was stronger near the end when the groups tried to make a new project. Pride was evident only in the group that got the farthest even though they did not know they had gotten the farthest. Intimidation appeared to be more obvious in the less confident I1 however, some risk taking was observed in her. The groups took risks but only after discussing and predicting what the results would be.

The understanding gleaned from this qualitative research study has only begun to crack the surface. Time, more research experience, and further data collection and analysis are necessary in order to contribute to understanding how selected female, high school biology students' process the ASM CD-ROM imagebase. The data from these few observations seemed to grow overnight, and interest in the project was continually stimulated. After many days and hours of work, the realization is that there is more work to be done.

In the future dissertation study, students will be observed working in pairs rather than in threes. This was recommended by the participants as a better group size for close computer work. The participants also suggested that the program possibilities be explained to the students prior to processing. The information revealed through this study would facilitate the larger dissertation study.

## **APPENDIX F**

### **LETTER TO MIDDLE SCHOOL PRINCIPALS**

February 22, 2000

Principal  
Granite Middle School  
Any Street  
Deep South City

Dear Principal,

I am completing research for my doctoral degree at LSU in Curriculum and Instruction and Microbiology. This study examines how effective three instructional strategies are in helping high school female biology students learn microbiology concepts. Biology students at Millville Academy have studied the concept of biofilms and have developed projects to explain specific biofilms to their peers. I have enclosed a copy of the abstract of the research study for your information.

A continuation of the study is to have some of these students use an instructional video and their projects to teach middle school students about biofilms. My research examines how this cross-age teaching impacts the high school students. I am currently scheduling sixth grade science classes for groups of my biology students to teach and would like to know if they could teach at Granite Middle School. We will be teaching these classes on Thursday, March 9<sup>th</sup> and Friday, March 10<sup>th</sup>. Several students have expressed an interest in going to your school. If this is possible, I would like to talk with the science teacher whose classes would be involved and explain the project in more detail.

Because these cross-age teaching sessions will be videotaped, parental permission and student assent of the middle school students is required. The results of this study will be published in a dissertation; therefore the name of the school and any information obtained will be anonymous.

I welcome the participation of your students in this project. Please expect a follow-up call from me after you receive this request. At that time I will be happy to answer any questions you might have. Thank you.

Sincerely,

Jo Dale Ales, Science Department  
Millville Academy

## APPENDIX G

### EXEMPTION FROM INSTITUTIONAL OVERSIGHT

IRB accession #: \_\_\_\_\_

LSU Proposal #: \_\_\_\_\_

#### LSU/PBRC: HUMAN RESEARCH SUBJECTS

#### APPLICATION FOR EXEMPTION FROM INSTITUTIONAL OVERSIGHT

ALL LSU/PBRC research using living human subjects, or samples or data, obtained from them, directly or indirectly, with or without their consent, must either be approved in advance by the LSU/PBRC Institutional Review Board (IRB), or be found to meet narrow criteria for exemption from IRB oversight by a designated committee.

This Form will help the PI to determine if the project is likely to meet the criteria for exemption, to present the case for exemption to a Screening Committee, and to document the decision on the request. NOTE: A determination of Exempt status does not release the researcher from exercise of prudent practice in protecting the interests of research subjects. Whether exempt or not, the research must be conducted according to the Ethical Principles and Guidelines for the Protection of Human Subjects (the Belmont Report, available from the Office of Sponsored Research); you must be familiar with the Principles.

Instructions: Complete checklist, pp 2-4. If project appears to qualify for exemption, complete this page and forward 2 ccs of entire form and a detailed project description adequate to document the responses in Parts A & B to a Screening Committee or IRB member. If ineligible for exemption, submit to IRB (see foot p. 4).

Principal Investigator Jo Dale H. Ales

Department/Unit Curriculum & Instruction Ph: 388-6867

Project Title Female High School Biology Students' Biofilm-Focused Learning: The Contributions of Three Instructional Strategies to Patterns in Understanding/Motivation  
~~Agency expected to fund project~~

I certify that the following responses are an accurate representation of the character of the project as planned. (If the project scope or design is later changed I will resubmit for review):

Signature Jo Dale H. Ales date 3/23/00 Principal Investigator  
(no per signatures)

Screening Committee Action: Exempted ☒ Not Exempted ☐

Name Petra Munoz Signature Petra Munoz Date 4/16/2000

\*Note reason; PI must send to IRB for review (See foot p. 4)

**APPENDIX H**  
**STUDENT CONSENT LETTER AND FORM**

Date \_\_\_\_\_

Dear Parents and Students,

As completion of the requirements for a doctoral degree in Curriculum and Instruction at Louisiana State University I will be conducting research at Millville Academy. Students in the biology classes are participating in a study of biofilms and their role in the natural world. I will be evaluating three types of instructional strategies to determine what strategies are more effective in helping students learn microbiology concepts. One strategy is for the high school biology students to cross-age teach middle school students. The biology students will be at \_\_\_\_\_ School on \_\_\_\_\_ to teach Ms/Mr. \_\_\_\_\_ science classes. Observations will be made and videotaped during the science class.

Though the focus of this research study is the high school students' learning, their teacher will also give the middle school students a pre-test and posttest. A comparison of middle school student responses on the two tests will be made in order to determine whether learning occurred.

It is anticipated that the results of this study will contribute to the body of knowledge of how students learn and are motivated in science. Student and school anonymity will be preserved at all times and the results of the study will be published in a written dissertation.

Participation is voluntary and anyone who chooses not to participate in or to withdraw from the study will receive no penalty. Please sign and return the attached parental permission form to your daughter's/son's teacher by \_\_\_\_\_ so that she/he may participate in the cross-age teaching.

Should you desire more information regarding the study, please contact me at Millville Academy. Thank you for your assistance with this project.

Sincerely,

Jo Dale Ales, Science Department  
Millville Academy



**APPENDIX I**  
**PARENTAL PERMISSION FORM**

I hereby give LSU Department of Curriculum and Instruction researcher, Jo Dale Ales (Doctoral Candidate) permission to observe and/or interview my child, \_\_\_\_\_ while she/he is participating in learning activities in biology. Observations and/or interviews will be videotaped and/or audiotaped. Some samples of student work may be collected. These observations will in no way affect the student's grade and the student's participation is voluntary. The name of the school and information obtained from the student will be anonymous. General data collected from the student will be shared with the school's administration and Public Television Station and analyzed in a written dissertation. The results of the study will be made available to you and your child.

\_\_\_\_\_  
Parent's Signature

\_\_\_\_\_  
Date

## APPENDIX J

### PRE-POSTTEST ON SELECTED MICROBIOLOGY CONCEPTS AND PRINCIPLES

NAME \_\_\_\_\_ DATE \_\_\_\_\_ PERIOD \_\_\_\_\_

#### BIOFILMS

The following questions are to assess what you know about biofilms. You will not receive a grade on this evaluation. Answer each question as best you can.

Multiple Choice. Write the letter of the best answer in the numbered blank. Use capital letters.

1. \_\_\_\_\_ Microbiology is the study of:  
A. algae                      B. protozoans  
C. bacteria                  D. All of the above
2. \_\_\_\_\_ Which statement best applies to a **community**?  
A. It consists of closely related individuals that can interbreed.  
B. It is made up of members of the same species.  
C. Many different species in an area make up a community.  
D. Communities include all of the living and nonliving things in a certain area.
3. \_\_\_\_\_ Ecology can best be described as:  
A. the study of the environment  
B. the study of living things in a certain area  
C. the interactions of living things in a certain area  
D. interrelationships between living things and their environment
4. \_\_\_\_\_ A transmission electron microscope is needed to observe:  
A. a colony of bacteria  
B. the organelles inside a bacterial cell  
C. a single bacterial cell  
D. bacteria that have flagella
5. \_\_\_\_\_ The father of microbiology is considered to be:  
A. Leeuwenhoek  
B. Louis Pasteur  
C. Edward Jenner  
D. Robert Hook

6. \_\_\_\_\_ Scientists study bacteria:
- A. only in a research lab
  - B. in foods
  - C. in their natural environment
  - D. in all types of environments
7. \_\_\_\_\_ Which statement about bacteria is likely to be false?
- A. They can be found in hot springs, deep in the ocean, and in glaciers.
  - B. Bacteria are used in biotechnology.
  - C. The first cells on Earth were probably bacteria.
  - D. Most bacteria are harmful to humans.
8. \_\_\_\_\_ Which statement about bacteria is false?
- A. do not contain DNA
  - B. are invisible to the naked eye.
  - C. reproduce by dividing in half.
  - D. can cause disease in animals
9. \_\_\_\_\_ Which of the following is the most inclusive group?
- A. microorganisms
  - B. bacteria
  - C. streptococcus
  - D. a pure culture of bacteria
10. \_\_\_\_\_ Which figure more closely represents the size of many bacteria?
- A. 5 nm
  - B. 5 - 10  $\mu$
  - C. 1,000,000 mm
  - D. 10 cm

Short Answer Answer the following, using complete sentences.

1. A biofilm is \_\_\_\_\_.
2. Several unusual places where you might find bacteria are \_\_\_\_\_
- \_\_\_\_\_
3. Agree or disagree with the following statement. **Bacteria are harmful and we should protect ourselves from them.** Use scientific principles to support your statement.
- \_\_\_\_\_
- \_\_\_\_\_

4. Explain how the following are used in studying bacteria. (1) pure culture  
(2) dyes and stains (3) biofilms

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5. What is the first thing that comes to mind when you think of bacteria?

---

6. How interested are you in finding out more about bacteria and biofilms?

---

7. Have you studied bacteria before? \_\_\_\_\_ If yes, when and where?

---

8. List up to 5 facts about bacteria and explain them.

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9. Describe something you have heard on the news about bacteria.

---

10. Name as many different ways to destroy bacteria that you can.

---

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11. What are some things you would like to know about bacteria?

---

---

12. Draw a diagram of a bacterium in the space below and label its structures.



## APPENDIX K

### TYPES OF BIOFILM IMAGE PRODUCTS

| Type                          | Category       | Scientific Name                                | Use of Image               | Additional                             |
|-------------------------------|----------------|--|----------------------------|--|
| Bioluminescent Biofilm        | Environmental  | <i>V. fischeri</i>                             | Poster/Display Board       | black light                            |
| Bioluminescent Biofilm        | Environmental  | <i>V. fischeri</i>                             | poster                     | 3D model, black light                  |
| Bioluminescent Biofilm        | Environmental  | <i>V. fischeri</i>                             | PowerPoint                 | black light                            |
| Dental Plaque                 | Medical/Dental |  | Display Board              | tooth brushes,<br>guides to tooth care |
| Dental Plaque                 | Medical/Dental |  | Display Board              | microscope slide, 3D model             |
| Dental Plaque                 | Medical/Dental |  | Posters                    | props, costumes, handouts              |
| Alpine Aquatic Biofilm        | Environmental  |  | PowerPoint                 | poster, diorama                        |
| Alpine Aquatic Biofilm        | Environmental  |  | PowerPoint                 | poster                                 |
| Plant Roots                   | Environmental  |  | Poster                     | vase with flowers,<br>microscope slide |
| Mouse Intestine               | Medical/Dental | <i>G. lamblia</i>                              | 3D posters                 |  |
| Indwelling Vascular Catheters | Medical/Dental | <i>P. aeruginosa</i> ,<br><i>S. epidemidis</i> | Poster (black/white image) | 3D model                               |
| Bioremediation                | Environmental  |  | PowerPoint                 |  |
| Contact Lens Case             | Medical/Dental |  | Poster                     | professional model<br>of contact lens  |
| Contact Lens Case             | Medical/Dental | <i>Acanthamoeba</i>                            | PowerPoint with sound      | 3D model using Styrofoam               |
| Food Borne Pathogen           | Medical/Dental | <i>L. monocytogenes</i>                        | PowerPoint, posters        | 3D model (candy) on poster             |
| Food Borne Pathogen           | Medical/Dental | <i>L. monocytogenes</i>                        | 3D Model of refrigerator   |  |
| Dental Equipment              | Medical/Dental |  |                            |  |
| Biofilm on Rocks              | Environmental  |  | Poster                     |  |
| Respiratory Track             | Medical/Dental |  | 3D model of resp. track    |  |

## **APPENDIX L**

### **BIOFILM IMAGE PROJECT TEACHER/STUDENT CONSTRUCTED RUBRICS**

#### **A. Presentation**

##### **1. Information**

- ☐ Clear
- ☐ Organized
- ☐ Accurate
- ☐ Complete (content on checklist included)

##### **2. Communication Skills**

- ☐ Organized
- ☐ Prepared
- ☐ Creative
- ☐ Spoken, not read
- ☐ Made eye contact with audience
- ☐ Spoke clearly and loudly
- ☐ Group cohesiveness

#### **B. Image Product**

- ☐ Creative
- ☐ It enhanced understanding
- ☐ Neat
- ☐ Organized
- ☐ Accurate
- ☐ Clearly labeled
- ☐ Image was appropriately used

#### **C. Communication with Biofilm Researcher**

- ☐ researcher provided information
- ☐ student questions were appropriate
- ☐ records were kept
- ☐ thank you was sent to researcher

## APPENDIX M

### PEER EVALUATION FORM

**PROJECT TITLE:** \_\_\_\_\_

**GROUP MEMBERS:** \_\_\_\_\_

Please rate your contribution to the group and evaluate the group on a scale from 1 – 10 with 10 being the highest.

**INDIVIDUAL EVALUATION: Name** \_\_\_\_\_

- |  |                                     |
|--|-------------------------------------|
| ____ 1. Following teacher's instructions   | ____ 7. Sharing responsibilities    |
| ____ 2. Asking meaningful questions        | ____ 8. Respecting others           |
| ____ 3. Contributing ideas and information | ____ 9. Explaining things to others |
| ____ 4. Helping the group stay on task     | ____ 10. Doing things on time       |
| ____ 5. Contributing materials             | ____ 11. Doing my best              |
| ____ 6. Asking for help when needed        |                                     |

I could improve on \_\_\_\_\_

I rank my contributions to the group as \_\_\_\_\_.

#### GROUP EVALUATION:

- |   |   |
|---|---|
| ____ 1. Following teacher's instructions      | ____ 6. Respecting others                 |
| ____ 2. Asking meaningful questions           | ____ 7. Explaining things to others       |
| ____ 3. Contributing ideas and information    | ____ 8. Solving problems within the group |
| ____ 4. Staying on task and meeting deadlines | ____ 9. Consistent effort                 |
| ____ 5. Sharing responsibilities              | ____ 10. Producing a quality product      |

I rank our group's efforts at working together as \_\_\_\_\_



## **APPENDIX N**

### **LETTER TO EDUCATION DIRECTOR OF PUBLIC TELEVISION STATION**

Mr. Education  
Public Television Station  
Any Street  
Deep South

April 8, 1999

Dear Mr. Education,

To follow up your recent conversation with \_\_\_\_\_, I am requesting permission to use the Enviro-Tacklebox biofilm technology video (from Module I) with teachers and students in the early fall of 1999 as part of my doctoral research at LSU. My advisor, Dr. James Wandersee, has suggested that the video could serve as an additional component to my research, which will use an American Society of Microbiology CD database of biofilm images and a related web site. This arrangement could be beneficial to LPB and the Enviro-Tacklebox™ project as well as to the teachers and students who would field-test the video.

The video will be used at middle school test sites in the Catholic Diocese of Baton Rouge by an estimated 10 teachers and 200 students. The instrument used and data collected from the dissertation research will be made available to LPB. This cooperative agreement will advance current knowledge of student learning and contribute to the success of the Enviro-Tacklebox™ project.

Thank you for your attention to this matter.

Sincerely,

Jo Dale Ales

## **APPENDIX O**

### **INSTRUCTIONS FOR CROSS-AGE TEACHERS**

1. Before you go to the middle school the teacher will give the students the pre-test.
2. Keep these teaching pointers in mind:
  - a) Human Beings are meaning makers.
  - b) Knowledge of objects and events in science cannot be transferred directly from a teacher's mind to a student's mind.
  - c) Your students have prior knowledge.
  - d) Your job is to help them connect their experience with biofilms (through your presentation) to what they already know. This will help them learn about biofilms and microbiology.
  - e) Visual images + verbal information help us remember better.
  - f) When the student actively participates, interacts, and reflects on her/his experience she/he has more meaningful learning and a deeper understanding.
  - g) Each learner is a unique individual and teachers must build a social environment that supports and encourages each learner's contributions.
  - h) School science should stress learning only a few concepts well and understanding and connecting concepts instead of memorizing.
3. Your presentation should be organized and follow this sequence:
  - a) Introduce your group members.
  - b) Briefly explain what you are going to do (overview).
  - c) Show the video A Biofilm's Bio. Pause and explain concepts during the video.
  - d) Present your image project and explain how it is connected to the larger concept of biofilms and microbiology.
  - e) Encourage questions from the audience. Answer questions.
  - f) Thank them for allowing you the opportunity to present your project.
4. Wear your school uniform and meet at the school office at the assigned time. Be courteous and polite.
5. You may be videotaped. Later I will interview some of you about your experience as a teacher.
6. In about one month you will take a posttest on biofilms and microbiology concepts.

Thank You!

## **APPENDIX P**

### **MILLVILLE CONSENT FORM**

#### **PARENT/STUDENT HANDBOOK ACKNOWLEDGMENT FORM**

The following statements signify that both parents and students have read the handbook and understand and agree to follow the school's regulations and to respect the school's positions regarding special requirements.

As parent(s)/guardian(s), I/we have read the 1999-2001 *Parent/Student Handbook* and understand the I/we are to cooperate with the school according to the policies and regulations contained therein. I/we have read and will abide by the guidelines outlined in the technology policy contained in this handbook. I/we understand that this access to technology is designed for educational purposes and that any violation of the regulations by my/our child is unethical and may result in the loss of usage privileges, cost to repair and disciplinary action.

I/We further understand that, for the good of the entire school community, the Millville administration may, from time to time, deem it necessary to establish special requirements (i.e. counseling, summer programs) regarding my/our daughter's continued attendance at Millville. I/We agree to abide by the requirements.

As a student of Millville, I have read the 1999-2001 *Parent/Student Handbook*. I agree to be accountable for the policies and regulations contained therein. This agreement includes the regulations regarding bus transportation and the guidelines outlined in the technology policy contained in this handbook. I understand that this access to technology is designed for educational purposes and that any violation of the regulations is unethical and may result in the loss of usage privileges, cost to repair and disciplinary action.

|                                    |                |
|------------------------------------|----------------|
| _____<br>Parent's Signature        | _____<br>Date  |
| _____<br>Parent's Signature        | _____<br>Date  |
| _____<br>Student's Signature       | _____<br>Date  |
| _____<br>Bus Route (if applicable) | _____<br>Grade |

## **APPENDIX Q**

### **SELECTED MICROBIOLOGY CONCEPTS AND PRINCIPLES**

1. Microbiology is the study of microscopic forms of bacteria, algae, protozoans, and fungi (i.e., microorganisms).
2. Microorganisms are diverse and ubiquitous.
3. Bacteria are prokaryotes and were the first cells on Earth.
4. Biofilms are communities of microorganisms that grow on surfaces in aqueous environments and are attached to each other and the surface by a polysaccharide matrix that the microorganisms produce.
5. Microorganisms recycle nutrients and are significant components of food chains and food webs.
6. Biofilms can be classified as medical, environmental, or industrial biofilms.
7. Some microorganisms are harmful and some are beneficial to humans.
8. Most microorganisms cannot be seen by the naked eye, so special technologies must be used to observe them.
9. Microorganisms can be controlled through the use of certain chemicals and antibiotics.
10. Some microorganisms are aerobic and some are anaerobic.

## **APPENDIX R**

### **CORRELATION OF SELECTED MICROBIOLOGY CONCEPTS AND PRINCIPLES TO THE NATIONAL SCIENCE EDUCATION STANDARDS (NRC, 1996)**

#### **Content Standard C: Life Science**

Interdependence of Organisms  
Matter, Energy and Organization in Living Systems  
The Cell

#### **Content Standard E: Science and Technology**

Understanding Science and Technology

#### **Content Standard F: Personal and Social Perspectives**

Personal and Community Health  
Environmental Quality

#### **Content Standard G: History and Nature of Science**

Science as a Human Endeavor

## APPENDIX S

### HOW THE CUTTING-EDGE SCIENCE OF BIOFILM RESEARCH ENGAGED STUDENTS IN LEARNING MICROBIOLOGY

| <u>Context</u>   | <u>Vision of learning</u> |               |               |               | <u>Tasks</u> |                 |                | <u>Assessment</u>    |             |              |              | <u>Instructional Model</u> |             |
|------------------|---------------------------|---------------|---------------|---------------|--------------|-----------------|----------------|----------------------|-------------|--------------|--------------|----------------------------|-------------|
|                  | <u>Resp. for learning</u> | <u>Strat.</u> | <u>Energ.</u> | <u>Colla.</u> | <u>Auth.</u> | <u>Challen.</u> | <u>Multid.</u> | <u>Perform-based</u> | <u>Gen.</u> | <u>Ongo.</u> | <u>Equi.</u> | <u>Interact.</u>           | <u>Gen.</u> |
| <u>Class</u>     | *                         | *             | *             | *             | *            | *               | *              | /                    | /           | *            | *            | *                          | *           |
| <u>Coop gp.</u>  | *                         | *             | *             | *             | *            | */-             | *              | /                    | *           | *            | *            | *                          | *           |
| <u>P presen.</u> | *                         | *             | *             | *             | *            | *               | *              | *                    | *           | *            | *            | *                          | *           |
| <u>CAT</u>       | *                         | *             | *             | *             | *            | *               | *              | *                    | *           | *            | *            | *                          | *           |

Note. R = responsible for learning

I = interactive

Co = co-learner

S = strategic

K = knowledge building

E = energized by learning

Em = empathetic

C = collaboration

H = heterogeneous

A = authentic

F = flexible

Ch = challenging

Ex = explorer

M = multidisciplinary

Cog = cognitive

P = performance-based

T = teacher

G = generative

Pr = producer

O = ongoing

Fac = facilitator

Eq = equitable

Gui = guide

| <u>Learning Context</u> |              |               | <u>Grouping</u> |              |            | <u>Student roles</u> |              |              | <u>Teacher roles</u> |                         |
|-------------------------|--------------|---------------|-----------------|--------------|------------|----------------------|--------------|--------------|----------------------|-------------------------|
| <u>Coll.</u>            | <u>Empa.</u> | <u>Heter.</u> | <u>Equi.</u>    | <u>Flex.</u> | <u>Ex.</u> | <u>Cog.</u>          | <u>Teac.</u> | <u>Prod.</u> | <u>Facil.</u>        | <u>Guid.</u> <u>Co-</u> |
| *                       | *            | /             | *               | /            | *          | *                    | /            | /            | *                    | *                       |
| *                       | *            | *             | *               | /            | *          | */-                  | /            | *            | *                    | *                       |
| *                       | *            | *             | *               | /            | *          | /                    | *            | *            | *                    | *                       |
| *                       | *            | *             | *               | /            | *          | /                    | *            | *            | *                    | *                       |

## APPENDIX T

### INTERACTIVE COMMUNICATIONS

| Student Request   | Researcher Action                                    |
|---|--|
| Help me find general information about biofilms.              | Sent web addresses                                   |
| Can you send information and images about a specific biofilm? | Sent References to journals and texts                |
| Can you answer these 5 questions?                             | Cited journal that had references                    |
| Can you answer these 15 questions?                            | Answered questions                                   |
| Do you know who could help me?                                | Referred to encyclopedia                             |
| Please send us some information.                              | Sent Web addresses                                   |
|   | Sent book title and where to find it                 |
|   | Got graduate student to send information             |
|   | Sent Email address of other researcher               |
|   | Sent abstract of journal article                     |
|   | Referred to web address of professional organization |
|   | Sent journal article as attachment                   |
|   | No longer working in the field                       |
|   | Don't know anything about it                         |
|   | Got it too late                                      |
|   | No response  |



## **APPENDIX U**

### **BIOFILM PROJECT COMPLETION CHECKLIST**

Does your biofilm image project answer the following question: What do people need to know about biofilms? How can we teach others about biofilms? What is a biofilm?

Your project should include the following information. Check off each item that your group has completed.

- \_\_\_\_\_ 1. What type of biofilm (environmental, medical, or industrial) is it?
- \_\_\_\_\_ 2. Where can it be found?
- \_\_\_\_\_ 3. What are the effects of this specific biofilm? Is it harmful or helpful. Explain your answer.
- \_\_\_\_\_ 4. Describe how this biofilm interacts with its environment. For example, it gets nutrients dissolved in the water that flows over it.
- \_\_\_\_\_ 5. How are the organisms in the biofilm interdependent? Example, they band together and are protected from antibiotics.
- \_\_\_\_\_ 6. What species are in this biofilm?
- \_\_\_\_\_ 7. Is this biofilm a population, a community, an ecosystem?
- \_\_\_\_\_ 8. What is the scientific name of the organism in your image? What kingdom is it in?
- \_\_\_\_\_ 9. What role do the organisms in your biofilm play in food chains and food webs?
- \_\_\_\_\_ 10. How does the biofilm grow? How do the cells reproduce?
- \_\_\_\_\_ 11. What are the physical characteristics of this biofilm?
- \_\_\_\_\_ 12. What causes this biofilm to form?
- \_\_\_\_\_ 13. How can this biofilm be prevented or removed?
- \_\_\_\_\_ 14. How large are the cells in this biofilm?
- \_\_\_\_\_ 15. What is the most interesting fact about this biofilm?

- \_\_\_\_16. What is the scale of your image or model?
- \_\_\_\_17. How was the image taken? What technology was used?
- \_\_\_\_18. Who donated the image?
- \_\_\_\_19. Why did your group select this image?

# APPENDIX V

## CHECKLIST MATRIX: CRITERIA FOR TEACHER-RESEARCHER EVALUATION OF ASM IMAGEBASE

| <u>Image</u> | <u>Number</u> | <u>Type</u>  | <u>View</u>                         | <u>Relevance to students</u>              | <u>Can be used in</u>                                    | <u>Quality</u>   | <u>Illustrates scientific concepts</u>     |
|--------------|---------------|--|-------------------------------------|---|--|--|--|
|              | 75            | camera,microscope, scanning electron microscope (SEM), confocal scanning laser microscope (CSLM) | ecosystem, macroscopic, microscopic | medical/dental, environmental, industrial | word processed document, presentation software, Internet | peer reviewed, sicientists around world, funding         | ecology, microbiology, technology, biology |
| <u>Text</u>  |               | information, glossary, navigation instructions, author identification, other resources, contacts | general or specific                 | sometimes too advanced or incomplete      | developing student explantions (plagiarism)              | peer reviewed, sicientists around world, funding support | ecology, microbiology, technology, biology |

## **APPENDIX W**

### **INTERVIEW QUESTIONS**

#### **Cross-Age Teachers**

1. Why did you want to teach the middle school students?
2. Describe your thoughts before teaching. How did the real teaching compare to these ideas?
3. You taught these students about biofilms, something that they knew very little, if anything about. In a sense you were the expert on your particular biofilm. Explain the degree of confidence you had in being the expert before your presentation. Explain whether your confidence level changed as a result of your teaching experience.
4. Explain whether you thought that you were successful in teaching these students about biofilms and microorganisms.
5. Describe your strong points in presenting the material to the students?
6. What areas could you have improved on and how do you think you could have?
7. Explain how this teaching experience affected your knowledge of biofilms.
8. How do you think this teaching experience has affected your interest in learning about biofilms? About science in general?
9. Describe any recommendations you would make to students who might teach middle school students in the future.
10. How would you rank the level of importance of the ways you learned about biofilms (your image project, contacting a scientist, teaching your peers, teaching middle school students) to your understanding of biofilms? In other words, which seemed to help you learn better? Can you explain your rankings?
11. Describe any changes in your interest in learning science that may have resulted from teaching the middle school students.
12. Now, let's construct a concept map on biofilms based on what you have learned in class and through the teaching experience. Use "biofilms" as the superordinate concept.

### **Middle School Teachers**

1. Since you know your students well, describe their level of interest in biofilms before and after the high school students' teaching sessions.
2. Describe their levels of understanding about biofilms before and after the teaching sessions.
3. Describe the levels of understanding that the high school students overall appeared to have about: a) biofilms, b) ecology, and c) general microbiology concepts. Describe the areas of strengths and weaknesses.
4. Describe what you perceive to be the strengths and weaknesses of the presentations.
5. Explain how successful you think the teaching was in terms of the knowledge about biofilms that you and/or your students gained?
6. Describe any recommendations you have that could possibly make the teaching sessions more effective for the middle school students? Base your recommendations on what you know about how students learn.
7. Describe any recommendations you have that could possibly make the teaching sessions more effective for the high school students? Base your recommendations on what you know about how students learn.
8. Explain why you might, or might not, want to have high school students teach your classes about any science concepts in the future.
9. Please comment on any areas that we have not talked about that you think are important to a successful cross-age teaching experience.

## APPENDIX X

### BIOFILM IMAGE PROJECT STUDENT PARTICIPANT DEBRIEFING

NAME \_\_\_\_\_ TEACHER \_\_\_\_\_ PERIOD \_\_\_\_\_ DATE \_\_\_\_\_

Presentation Title: \_\_\_\_\_

Description of Presentation: \_\_\_\_\_

Answer the following questions about your project presentation.

1. Do you think that your presentation contributed to **your** understanding of biofilms and microbiology? Explain your answer.

\_\_\_\_\_

2. Do you think that your presentation contributed to your **classmates'** understanding of biofilms and microbiology? Explain your answer.

\_\_\_\_\_

3. What did you like best about your presentation and why?

\_\_\_\_\_

\_\_\_\_\_

4. What were the strengths of your presentation and why?

\_\_\_\_\_

5. Explain what you would do to improve it.

\_\_\_\_\_

6. Which project presentation did you like the best and why?

\_\_\_\_\_

\_\_\_\_\_

7. Which biofilm was the most interesting to you and why?

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8. How easy do you think it was to communicate with a scientist and why?

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9. How helpful was a scientist to your understanding and why?

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10. How helpful were the images to your understanding of biofilms and microbiology?

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11. Is there anything you would change about the ASM's online images and information?

Explain. \_\_\_\_\_

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12. How helpful was the video, A Biofilm's Bio to your understanding and why?

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12. Is there anything you would change about the video?

Explain. \_\_\_\_\_

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14. Please write any additional comments in the space below.

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### High School Students' Typical Responses to Debriefing

1. Their presentation contributed to their own understanding of biofilms - 56 Yes, 13 No (Cross Age Teachers - 19/19 or 100% Yes)
2. Their presentation contributed to their peers' understanding of biofilms - 55 Yes, 12 No, 6 Unsure (They weren't always interested) (Cross Age Teachers - 16/19 or 89% Yes - three No because they weren't attentive)
3. Liked best about their presentation:
  - Creating and making the visual aid (ex - using glow in the dark "stuff", making the Jello model)
  - Presenting
  - The information (ex - the whole concept)
  - Being and working in a group
  - Nothing
4. Strengths of their presentation
  - Presentation skills (talked loud)
  - Knowledge and understanding of biofilms (quality of explanations, knowing the facts, depth of explanations)
  - Creativity (stickers, candies)
  - **Visual Aid (Posters, PowerPoint, Models)**
  - The group
  - The image
  - Organization and preparation
  - Extra material (books)
  - Equal talking time
  - None
5. What they would do to improve
  - Spend more time to prepare, to learn
  - Go into more detail
  - Do something hands on and make it fun (more interaction with audience, such as microscope slides)
  - Pick a different type of biofilm
  - Make it more fun
  - Get some adult help in designing the presentation
  - Be better prepared to present (practice)
  - Improve the visual aid design (too many words on poster)
  - Improve the quality of information (use smaller words)
  - Use more visuals and images
  - Get mentor to respond
  - Research more information

- Work better in the group
  - Make it more interesting
  - Allow more time for presentation
  - Be more organized
  - Be at school
  - Put it in terms that are easier to understand
  - Don't wait until the last minute
  - Explain more thoroughly
  - Make our poster neater
  - Nothing, it was great
6. Project they liked the best (in descending order)
- Dental Plaque (because of familiarity)
  - Bioluminescence
  - Others (Dental Equipment, Contact Lens, Food Borne Pathogens, Respiratory Track, Mouse Intestine, Biodegradation)
7. Project that was most interesting (in descending order)
- Dental Plaque (relative to them, easy to understand)
  - Bioluminescence
  - Others (Dental Equipment, Contact Lens, Food Borne Pathogens, Respiratory Track, Mouse Intestine, Biodegradation, Alpine Aquatic, Catheter Segment)
- 8 & 9. Relative success with contacting scientist mentor and getting information
- Did not respond
  - Difficult
    - Emailed several and only a few responded
    - Frustrating
    - They were rude
    - Gave use website addresses that were not accessible.
    - Talked very technically
    - Too busy and too important to answer our questions
    - Sent us nothing that had anything to do with our project
    - Did not answer in time
    - Computer wouldn't work
  - Easy (You get a chance to say what you need without any interruptions. He answered all our questions)
  - Gave us good websites and information
  - Responded quickly, explained all the little details
  - I liked looking it up myself better.
10. Contributions of images to their understanding of biofilms and Microbiology

- Some were helpful while others were not
  - They were too small and not labeled, blurry
  - Websites were better
  - The information was not very easy to understand
  - Most said images were very helpful (Good, the only thing we understood. Referred to being a visual learner. Helped get a picture image in mind, saw how and where they lived, how it glowed in the dark)
11. What they would change about the ASM online images and information
- Nothing
  - Get some good images of bioluminescent biofilms
  - Have a bigger variety of pictures and information
  - Needs more information about biofilms
  - Make it look like a fun site (use better illustrations)
  - Make them easier to obtain
  - Tell how all the pictures were taken (type of microscope)
  - Make them bigger
12. The degree to which the video was helpful.
- Do not remember it
  - Confusing
  - Explained biofilms in an easy to understand way (on our level)
  - Not helpful cause we watched it before we knew anything about biofilms
  - It gave us an introduction (pretty good base for learning about the biofilms we studied)
  - Gave the big picture
  - Showed examples
  - Gave a brief understanding
  - Moved too fast!
  - Did not like it, boring
13. Things they would change about the video
- Do not remember it
  - Nothing. The movie was cool.
  - Slow it down. (Too much information at one time)
  - Do not stop it every two seconds; see it the whole way through.
  - Don not have us take notes.
  - Kinda corny, immature, elementary, dorky
  - Good. I learned most of the information on biofilms from the video.
  - Less background music
  - Make it more interesting
  - Too much information packed into one video
14. Additional Comments

- Project was pointless
- Watch the video after we know something
- I did not like the project very much
- I did not understand it fully
- We spent too much time on it
- We didn't have a lot of time to learn about biofilms before we did the project.
- Wish the teachers had answered the questions we didn't know (Harper)
- I liked doing this project

## VITA

Jo Dale Hill Ales was born on August 15, 1947 in El Paso, Texas. She was the oldest of three daughters born to Dr. Roy F. Hill, Jr. and Dale Newsome Hill. She developed an early interest in science partly as a result of the influence of her father who was an anesthesiologist and her mother who was a nurse. She graduated from Louisiana State University with a bachelor of science degree in biology and chemistry education in 1969. She is married to attorney John F. Ales and they have three children, John Forrest Ales, Laura Katherine Ales, and Elizabeth Dale Nolan, and a son-in-law, Norman Nolan.

She was awarded a master of natural science degree in microbiology in August of 1972. She worked under the guidance of the late Dr. Robert Amborski and conducted cell and organ tissue research funded by a National Institutes of Health grant. Her work experience in the science field includes serving in forensic science as a serologist at the Louisiana State Police Crime Lab. She also worked as a medical researcher under Dr. James Fischer at Tulane University Medical School's Department of Pharmacology studied erythropoietin formation by rabbit bone marrow cells.

Jo Dale's teaching career has spanned 20 years with time taken off for her family. She has taught 6<sup>th</sup> grade through college level science in both public and private schools concentrating in the areas of genetics, chemistry, biology, advanced placement biology, and environmental science. She was a co-recipient of the 1999 National Teacher Training Institute Award for Louisiana and a 2000 Louisiana Finalist for the Presidential Award For Excellence in Science Education. She has been active in professional organizations, has presented numerous teacher workshops, and serves as an

educational consultant. She also served as a teacher ambassador to Finland and assisted in teaching environmental science instructional strategies.

Jo Dale began her program of doctoral study in 1996 under the guidance of Dr. James H Wandersee of the William H. LeBlanc Teaching Fellow in the Department of Curriculum and Instruction at Louisiana State University. She has co-authored several curriculum guides for science educators and serves as a Key Leader for Building a Presence in Louisiana. She was awarded the degree of Doctor of Philosophy in December, 2000.

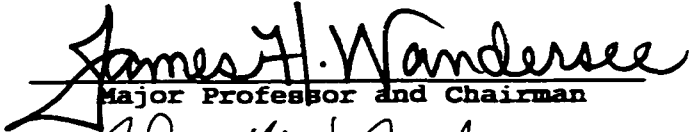
DOCTORAL EXAMINATION AND DISSERTATION REPORT


**Candidate:** JoDale Hill Ales

**Major Field:** Curriculum and Instruction



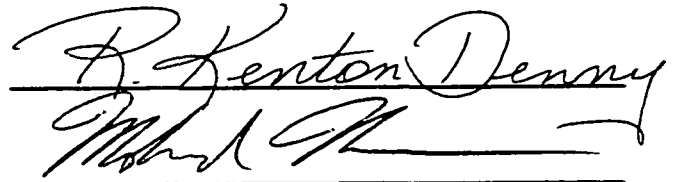

**Title of Dissertation:** Female High School Biology Students'  
Biofilm-Focused Learning: The Contributions of Three Instructional  
Strategies to Patterns in Understanding and Motivation

**Approved:**

  
Major Professor and Chairman

  
Dean of the Graduate School

**EXAMINING COMMITTEE:**

**Date of Examination:**

September 29, 2000